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A Study on Measuring Scientific Modeling Ability of Elementary School Students

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A R T I C L E I N F O

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A B S T R A C T

Scientific modeling ability is a core element of scientific literacy, taking the requirements of the Compulsory Science Curriculum Standards (2022 Edition) as an orientation, designing test questions for scientific modeling ability, and carrying out the relevant goodness-of-fit test through the Rasch model, the study found that the assessment tool can well reflect students' scientific modeling ability, and made suggestions on the teaching and learning of scientific modeling with regard to the relevant research, with a view to promoting elementary school students' development of scientific modeling ability.

Scientific thinking is the key to cultivating scientific and technological innovation talents, and scientific modeling, as an important part of scientific thinking, has been widely emphasized by researchers in the field of science education. Therefore, cultivating students' scientific modeling ability is the core of the development of school science education in the new era. Early researchers of scientific modeling mainly dissected the modeling process from the characteristics of scientists' empirical thinking, and advocated "analyzing consciousness and experience into many smallest basic elements to study"According to Hestenes (1992), scientific modeling is a "process knowledge" that is expressed in the application of certain design principles (scientific theories) to produce a model of an object or a model of a natural process, and the ability to model is the ability to use the four modeling elements: description, conceptualization, derivation, and validation Halloun (1996) endorsed this view and further developed the concept of diagrammatic modeling that the selection, construction, validation, analysis and utilization of models are five important elements in the problem solving process, and scientific modeling ability is the ability to use these modeling elements.Models provide a powerful tool with which to make sense of the world. Scientists use a variety of representations — including models — to explain or predict phenomena. A scientific model includes both abstraction and representation of the critical features and mechanisms of phenomena (Zhai, 2022). It represents a system that explains or predict phenomena (Shemwell & Capps, 2019), and can take a variety of forms; these can be categorized based on features, such as having a representational approach (e.g., drawings, graphs, diagrams), an epistemic purpose (e.g., explanatory or predictive), or a computational approach (e.g., system models or agent-based models; Harrison & Treagust, 2000). The Standards for Compulsory Education Science Curriculum (2022 Edition) takes scientific modeling as a key connotation of scientific thinking, and considers that scientific modeling is a kind of complex thinking construction ability, which is mainly reflected in the ability to abstract and generalize objective things based on experience, and then construct models, and analyze and interpret phenomena and data based on the models, describing the structure of a system, its relationships and the process of change The international science education emphasizes the importance of assessing students' ability to understand and understand scienceAnother function of models is communication—that is, models are a means to communicate one's understanding of phenomena. Given that human thoughts are invisible, one's understanding of phenomena must be expressed. In this process, one has to select the "modeling language," a form of representation that is understandable in the community. Such language can take the form of drawings (Tytler et al., 2020; Wilkerson-Jerde et al., 2015), graphs (Matuk et al., 2019), writing (Jong et al., 2015), simulations (Heijnes et al., 2018), mathematical formulas (Marshall & Carrejo, 2008), and so on. Such diverse multirepresentations increase one's opportunity to develop and improve explanations because of the enriched approaches to communication. Although models may be represented differently, they share commonalities, such as generativity. Scientific models should be generative, as the model constructed to explain one phenomenon must be able to explain other related phenomena or predict future phenomena (Schwarz et al., 2009). Scientific models support theory generation, as they help scientists conceptualize problems and mechanisms, and figure out solutions. International science education attaches importance to assessing students' scientific modeling ability, and some large-scale science education assessment programs have incorporated modeling as one of the essential attributes of science into the assessment of students' scientific practice.Some large-scale science education assessment programs have incorporated modeling as one of the essential attributes of science into the assessment of students' scientific practice. In addition, some researchers have measured students' understanding of models and modeling with the level of scientific modeling practice .Given the potential of modeling to improve science learning, it is essential to involve students in developing models.By developing models, students

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have opportunities to analyze, reason, synthesize evidence, and use scientific knowledge to explain and predict phenomena (Lehrer & Schauble, 2006b; Stratford et al., 1998). As such, models serve as representations of students' understanding.Through scientific modeling, students experience model construction, evaluation, testing, and use, mirroring the work that scientists do in their everyday practices (Lehrer & Schauble, 2012;Schwarz et al., 2017). Improving students' scientific modeling competence is therefore included in the Framework for K-12 Science Education (NRC, 2012). Scientific modeling is a popular research topic in international science education, and international research on students' scientific modeling ability has become increasingly mature; however, research on scientific modeling in China is still in its infancy, with a lack of empirical research on scientific modeling and few studies focusing on the assessment of students' scientific modeling ability. Given that scientific modeling plays a key role in the development of scientific thinking, it is of great theoretical significance and practical value to develop a localized scientific modeling ability assessment tool for Chinese students.

1.Research methodology

1.1 Measurement tool development

Grosslight(1991) used an interview method to investigate students' views of the nature of models Grosslight (1991) used an interview method to investigate students' understanding of the nature of models, focusing scientific modeling research on the understanding of the nature of models and emphasizing the development of students' view of the nature of models, which was a landmark in the development of scientific modeling assessment methods.Treagust (2002) investigated the understanding of models by 228 high school students, further exploring students' understanding of the nature of models. Van Driel(2002) investigated science teachers' knowledge of models and modeling. Gilbert and Justi (2003) referenced Grosslight et al. and used semi-structured interviews to investigate science teachers' views of the nature of modeling. The study was conducted by Gilbert and Justi (2003) using semi-structured interviews. Initially, scientific modeling research focused on students' and teachers' knowledge of models and emphasized the development of students' views of the nature of science, but as research continued, researchers in the field of science education began to focus on assessing students' scientific modeling abilities and the research gradually focused on specific subject matter. For example, Dori (2012) assessed the scientific modeling ability of high school students based on the content of "molecular structure" in chemistry (2012) assessed the scientific modeling ability of high school students based on "molecular structure" in chemistry. Yu (2021) used "ionization and ionic reactions" in chemistry as the test content to design scientific modeling ability test questions based on the curriculum standards.(2021) designed scientific modeling ability test questions based on curriculum standards using "ionization and ionic reactions" in chemistry as the test content. Wang (2022) developed a five-level scientific modeling competence assessment framework based on the physics discipline: using models directly, identifying models, selecting models, constructing models and creating models. Most of the existing scientific modeling assessment studies have targeted students at the secondary school level, and there is a lack of scientific modeling competence assessment tools specific to elementary school students. Therefore, based on the target requirements of scientific modeling in the Compulsory Education Science Curriculum Standards (2022 Edition), and implementing the core concept of comprehensively improving every student's scientific literacy, this study designed and developed a scientific modeling measurement test for primary school students, with the aim of filling in the gaps of existing studies.

This study refers to the logic of writing test questions for elementary school science in foreign countries, closely integrates with the content of domestic elementary school science teaching materials, and initially constructs the scientific modeling assessment questions after visiting the official websites of the four major examination bureaus in the United Kingdom and Edexcel, as well as the official websites of education in all 50 U.S. states, to collect the test papers of the science final exams and the stage exams for grades 4-6 in the years 2019-2022, and then, after several rounds of discussions within the subject matter group and organization of After several rounds of discussion within the group and organizing internal experts to review the test questions, the test questions were further revised and improved to identify three scenario-based questions for this scientific thinking assessment tool, all of which were expository in nature. After analyzing and discussing the test questions, the assessment scale of the test questions was designed based on the previous evaluation framework of scientific modeling ability, which was divided into three indicators, namely, model construction and use, model testing and revision, modeling metacognition and metamodeling knowledge. The test questions were first distributed on a small scale for pre-experimentation, the tools and contents were adjusted according to the experimental data, and finally a large-scale test was conducted in four districts, namely, Heishan, Linghe, Taihe and Gaoxin, in Jinzhou City, Liaoning Province, and the quality of the test tools was analyzed according to the experimental data.

1.2 Design of quiz questions

With reference to the Compulsory Science Curriculum Standards (2022 Edition), the geographic celestial motions were selected as the knowledge points to be examined for the design of the questions, which are as follows:

Scenario one examines the law of motion of the solar celestial bodies, based on the house orientation, directional information, the position of the sun and other information to set up three sub-topics, and gradually ascending to compare with other knowledge points, reflecting the modeling meta-cognitive knowledge and meta-modeling knowledge; Scenario two examines the angle of the Earth's yellow-deficit and the orbit of the relevant knowledge, the reasons for the change of the four seasons to make an explanation of the next three sub-topics; Scenario three examines the motion of the Scenario 3 examines the trajectories of the Sun, the Earth and the Moon, with three sub-questions. Students need to clarify the positional changes of the three and the celestial phenomena that occur during lunar eclipses, and to expand the related phenomena of lunar eclipses on this basis.

Based on the framework of scientific modeling elements of existing studies, this study considers and draws on a number of existing scientific modeling assessment tools, and concludes that scientific modeling ability includes three dimensions, namely, "model construction and use", "model checking and modification", "metacognition of modeling and metamodeling knowledge", It is believed that scientific modeling ability consists of three dimensions: "model construction and use", "model testing and revision", and "modeling metacognition and metamodeling knowledge". Based on these three dimensions, elementary school students' scientific modeling ability is measured at levels 1-3, and the grades of the students' scientific modeling ability are increased sequentially from level 1-3, and specific and operational definitions are given for each dimension at each level, thus forming the framework of the assessment.

2 Quality of research tools

2.1 Analysis of the overall quality of the assessment tool

In this study, SPSS 26. 0 and Winsetps 3.81.0 software were used to analyze the test data for Rasch modeling. The data of 1942 observations were imported into Winsetps 3.81.0 for computation, there were no missing values (non-response) in all observations, 10 subjects' (Person's) responses were considered to be extremely low rated, the remaining 1932 subjects' (Person's) responses were considered to be valid, and all the 9 evaluative items (Item) were estimated by the software.The Rasch model was mainly analyzes the overall quality of the instrument in terms of data and model fit indices (Infit and Outfit), Seperation and Reliability.

Table 1 Overall quality of the assessment tool

	TOTAL SCORE	COUNT	MEASURE	MODEL ERROR	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	9.6	9.0	.19	.60	1.00	.0	.99	.0
S.D.	4.2	.1	1.37	.10	.43	1.1	.43	1.0
MAX.	17.0	9.0	3.26	1.05	2.53	2.9	2.86	2.8
MIN.	1.0	6.0	-3.26	.53	.12	-3.7	.13	-3.7

REAL RMSE .66 TRUE SD 1.20 SEPARATION 1.82 PERSON RELIABILITY .77
MODEL RMSE .61 TRUE SD 1.23 SEPARATION 2.01 PERSON RELIABILITY .80
S.E. OF PERSON MEAN = .03

The mean (Infit) MNSQ = 1.00 and (Outfit) MNSQ = 0.99 in this test, which is within the standardized range (0.7-1.3) and close to 1. The mean (Infit) ZSTD = 0.00 and (Outfit) ZSTD = 0.00, which is within the standardized range (-2.0, +2.0), which indicates that both the subjects' and items' MNSQ and ZSTD are very satisfactory, indicating that the observations of the assessment tool fit well with Rasch's theoretical model. The mean value of subject ability was 0.19, which is higher than the mean value of item difficulty, 0, indicating that subject ability is higher than item difficulty, indicating that the assessment tool is overall simpler for subjects, but the gap is very small. The actual model subject separation (Separation) = 1.82, the standard model subject separation (Separation) = 2.01, in the standard value of 2 around a small difference. The standard value of model subjects' reliability coefficient is 0.7, the actual model subjects' reliability coefficient (Person Reliability) = 0.77, and the standard model subjects' reliability coefficient (Person Reliability) = 0.80, which are all greater than the standard value. The above parameter results indicate that the overall characteristics of the assessment tool are good and the tool can effectively test the scientific modeling ability of the subjects.

2.2 Unidimensionality and goodness of fit of the assessment instrument

The Rasch model is based on the assumption of unidimensionality, where subjects' scoring situation is related to only one of the subjects' abilities, so the questionnaire needs to pass the unidimensionality test. The unidimensionality of the data is established when the minimum eigenroot plants in the residual model are all less than 3. In addition, the entries are considered to meet the unidimensionality requirement when the value of the correlation between the probable influencing factors and the item scores is at [-0.4,0.4] .

As shown in the figure, the upper and lower case letters (A, B, C, D, E, a, b, c, d) represent the evaluation items in the tool, totaling 9. The horizontal coordinate is the item difficulty, and the vertical coordinate is the item loading coefficient, which should fall between the desirable values of -0.4 and +0.4, and those outside of this range are considered to be unsatisfactory to the requirement of unidimensionality. There were a total of three locations outside the region, and the rest of the test items fell between (-0.4, +0.4), which meets the requirement of unidimensionality.

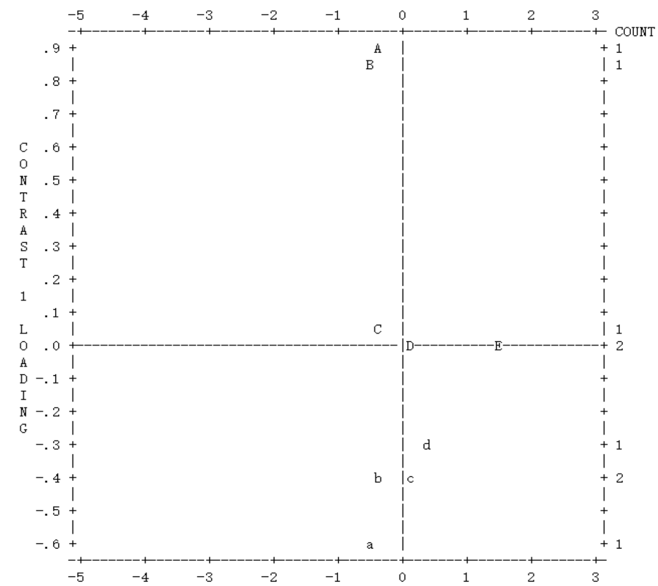

Fig. 2 Test item unidimensionality test

2.3 Rating scale structure

The horizontal coordinates of the scoring level structure graph indicate the difference between the subjects' modeling ability and the difficulty value of the item, and the vertical coordinates indicate the probability that a subject will answer with a certain score (0, 1, or 2). Threshold is the point where the curves cross in the graph, corresponding to the same vertical coordinate, indicating that subjects with the level of physical modeling ability corresponding to that point have an equal probability of scoring on both scores. From the hierarchical structure of Fig. 3, it can be seen that the 0-point curve has a decreasing probability of scoring with the increase of the subject's physical modeling ability, and the probability of scoring is 0 when the difference between the subject's ability and the difficulty of the item is greater than 1; the 2-point curve is the opposite of the situation, and the probability of scoring increases with the increase of the subject's physical modeling ability, and the probability of scoring is 0 when the difference is less than -1 or so; the 1-point curve has a decreasing probability of scoring with the increase of the subject's physical modeling ability. The 1-point curve increases with the subject's physical modeling ability, the score probability increases and then decreases, and there is a "peak" within the range of -0.5 to 0, and the peak is higher than the 0 and 2 curves, and the three curves shown in the figure cover a wider range of ability. From the above analysis, we know that the three scores of 0, 1 and 2 can well represent a certain category, which indicates that the pre-established scoring standard is more reasonable. Based on the above ideas, this study analyzes the scoring level structure charts of the remaining 9 items one by one, and finds that the scoring standards set are closer to the actual situation, and the scoring standards are formulated scientifically and reasonably.

In summary, all indicators of the evaluation tool reflect good characteristics, implying that the designed scientific modeling competence assessment tool can be used to measure the scientific modeling competence of the subjects.

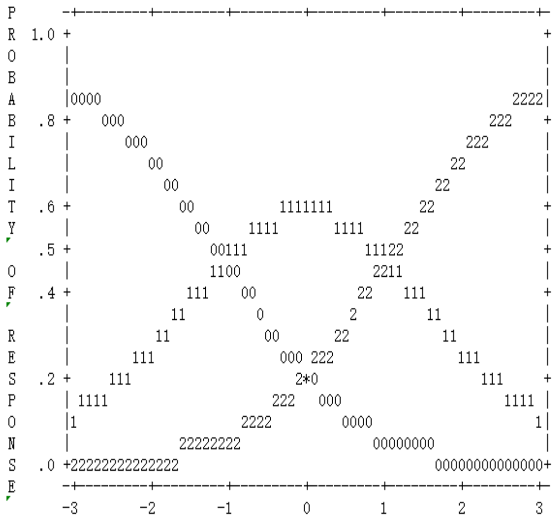

Fig. 3 Test item rating scale structure

2.4 Correspondence analysis of topic difficulty-subject ability

The Rasch model allows subjects' ability values and item difficulty values to be compared on the same scale by converting raw scores to logit scores. As shown in the figure, the item-person map visualizes the correspondence between subjects and items.The Wright plot provides information about the distribution of item difficulty matched to subjects' ability levels.The Wright plot lists the locations of 1942 students and 9 items on a generic scale. The first column is the logit scale, and columns 2 and 3 graphically depict the location of the subjects and the nine items, respectively.The Wright plot converts student scores and item scores in logit units on a generalized interval scale. For this study, student and item pair scales ranged from -4 to +3 logit. a "#" represents 23 individuals, "." represents 22 people, the right side is test item difficulty, and the left side is student level. Student proficiency and test question difficulty are mostly distributed between (-2, 2), which is close to 0. The overall quality of the data is very good. Inspection showed no large apparent gaps between items, indicating a good distribution of test question difficulty and good content adequacy and validity.

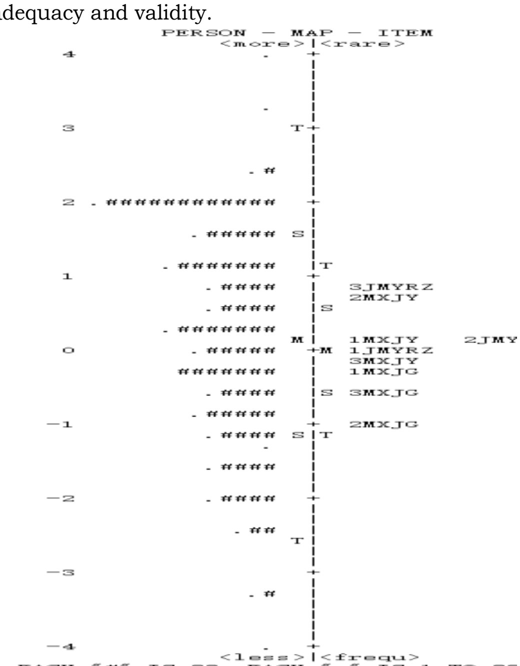

Fig4 Item-subject correspondence

3 Findings

3.1 Performance of scientific modeling capabilities

Students scored highest on the dimension "Model construction and use" (1.26), followed by "Model testing and revision" (0.98), and lastly, "Modeling metacognition and metamodeling knowledge" (0.95). " (0.95). This is shown in Table2 below.

Table 2 Descriptive statistics of scientific modeling skills

	average value	(statistics) standard deviation	skewness	kurtosis
Model construction and use	1.26	0.597	-0.636	-0.674
Model Testing and Correction	0.98	0.505	0.117	-0.991
Modeling metacognition and metamodeling knowledge	0.95	0.532	0.069	-0.714

The absolute value of the skewness of each of these dimensions is less than 1, indicating that the subjects' scores are more symmetrical; the skewness of the model construction and use dimensions is less than 0, with a higher number of people scoring below the mean on these dimensions. Overall, the subjects' scientific modeling ability has a medium flat standard deviation and a small kurtosis, and the test can distinguish between students with different abilities, with more people at the intermediate level. The absolute value of the skewness of each of the dimensions is less than 1, indicating that the subjects' scores are more symmetrical; the skewness of the model construction and use dimensions is less than 0, and the number of people who scored below the mean on these dimensions is higher. Overall, the flat standard deviation of the subjects' scientific modeling ability is medium and the kurtosis is small, and the test can distinguish between students with different abilities, with more people in the medium level.

Further analysis of the data by district, as shown in Figure 5, found that the Black Mountain District was outstanding in the scientific modeling ability of the four districts, with the mean values of the three dimensions ranking first, the mean value of "model construction and use" reached 1.55, and the mean values of the dimensions of "model checking and correction", "modeling metacognition and metamodeling knowledge" all reached more than 1.1, showing that the elementary school students in this district had excellent performance in scientific modeling ability. The mean value of "model construction and use" reaches 1.55, and the mean value of "model testing and revision" and "modeling metacognition and metamodeling knowledge" reaches more than 1.1, which shows that elementary school students in this region have excellent scientific modeling ability; Hi-tech Zone ranks second among the four districts, and the mean value of the three dimensions reaches more than 1, which shows that the students in this region have good scientific modeling performance ability; Lingling Zone ranks first in all three dimensions, with a mean value of 1 or more. Linghe and Taihe districts are a little behind in the four districts in terms of modeling ability, with the mean value of the three dimensions in Linghe district around 0.7, and the mean value of the "model construction and use" dimension in Taihe district reaches 1.14, while the rest of the dimensions are all below 1.

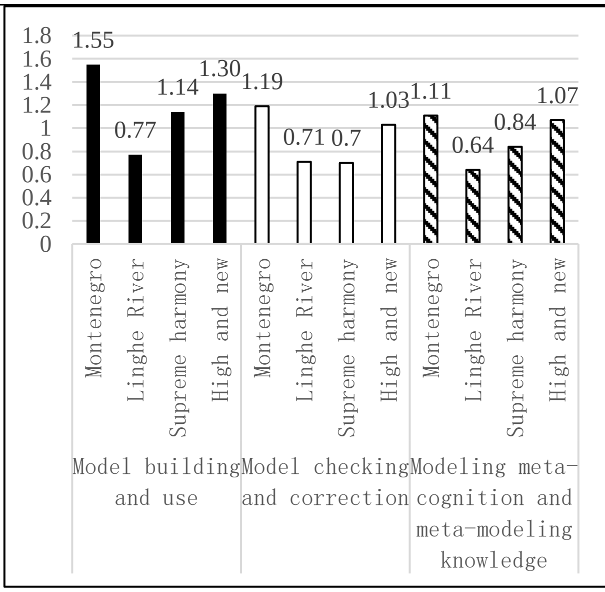

Fig. 5 Distribution of the mean value of students' scientific reasoning ability water in different regions

3.2 Relationship between science modeling competency sub-skills and science achievement

This study found that there is a significant correlation between geography-based scientific modeling skills and science achievement at the elementary level. The highest correlation was found for the dimension "model testing and revision" (r=0.140, p<0.01), followed by "modeling metacognition and metamodeling knowledge" (r=0.138, p<0.01), and finally "model construction and use" (r=0.105, p<0.01). Modeling competence also showed a certainpattern between these three sub-skills, with "model testing and revision" versus "model construction and use" (r=0.632, p<0.01), "model construction and use " versus "modeling metacognition and metamodeling knowledge" (r=0.679, p<0.01), "model testing and revision" versus "modeling metacognition and metamodeling knowledge " (r=0.649, p<0.01) all had correlation coefficients above 0.6. Overall, it seems that there is a linear correlation between elementary school students' scientific modeling skills and science achievement.

Table 3 Correlation between scientific modeling competency sub-skills and science achievement

	scientific achievements	Model construction and use	Model Testing and Correction	Modeling metacognition and metamodeling knowledge
scientific achievements	1			
Model construction and use	.105**	1		
Model Testing and Correction	.140**	.632**	1	
Modeling metacognition and metamodeling knowledge	.138**	.679**	.649**	1

4. Measurement results and recommendations

This test instrument performs well in terms of validity and differentiation, and the actual test results fit the model well. The test questions were rated on a good scale, effectively differentiating between the levels of different subjects on different dimensions. The correlation between science scores and scientific modeling is good in all dimensions, with significant correlation between all dimensions, especially the highest correlation in the dimension of "model testing and modification" (r=0.140, p<0.01). Based on this, this paper makes the following suggestions for teaching and learning scientific modeling:

4.1 Strengthening Teachers' Capacity to Teach Modeling

Teachers' content knowledge and pedagogical content knowledge affect the quality and types of activities integrated into their teaching (Van Driel and Verloop 1999). For instance, teachers exposed to rote memorization and factual repetition end up employing similar techniques in their lessons (Momsen et al. 2010). In scientific modeling instruction, teachers expect students to recall imposed models to demonstrate learning about science concepts and facts (Buckley 2012; Gilbert and Boulter 2000; Horikoshi 2015; Nassiff and Czerwinski 2014; Schwarz and Gwekwerere 2007). This teaching approach thwarts opportunities for students to engage in authentic scientific modeling practices. Offering professional learning on scientific modeling to preservice and in-service science teachers (Crawford and Cullin 2004; Dass et al. 2015; Kim and Oliver 2018; NRC 2012) to help them develop both content knowledge and pedagogical content knowledge (Weiss and Pasley 2006) is critical. During professional learning, teachers need opportunities to experience scientific modeling from a student's perspective as well as examine instructional methods and learning materials on scientific modeling (Stammen et al. 2018) from an educator's perspective.

Several challenges emerge in attempting to cultivate modeling practices in classrooms. First, students need an authentic reason for building a model other than ''doing school.'' Scientists create a model to help their own thinking and share their ideas with peers to test whether they are convincing in the professional community. In the case of our classroom materials, students are typically told when to create models, and their utility, if apparent, needs to emerge as they are used in their subsequent work. A second challenge emerges in giving students a real sense of audience for their models. On this front, we were partially successful, in that students reported the benefit of hearing their peers' ideas as models rather than just through open discussion.However, for the most part, students seemed to see their own models as being created for the teacher as just another form of ''science answer.'' They did not typically try to make a model to facilitate their own thinking or their own communication of ideas. A third challenge is in motivating the need to revise models. While students saw the point of making partial answers more complete or more correct, as with constructing models, the class was always told to revise their models. This effectively took the decisions about when their models were sufficient and when they need to be revised out of the students' hands.The teaching of scientific modeling involves the "teaching" of teachers and the "learning" of students, and the promotion of effective modeling teaching practices by teachers is a necessary way to develop students' scientific modeling ability. Promoting teachers to implement effective modeling teaching practices is a necessary way to develop students' scientific modeling ability. Therefore, in order to improve the quality of teaching and learning of scientific modeling, it is necessary to firstly strengthen the modeling teaching ability of teachers, so that teachers can fully utilize the modeling teaching method in their teaching practice. On the one hand, due to the complex activity characteristics of scientific modeling, teachers should flexibly use different teaching methods and design diversified teaching activities according to the teaching content in the teaching process. For example, in the teaching of geography, the teaching content involves the movement of celestial bodies, the distribution of ocean currents and other knowledge points, the teacher can show three-dimensional clear modeling teaching materials, encourage students to use modeling to solve problems, enhance the students' ability to construct and use the model and promote the accumulation of students' metacognition of modeling and meta-modeling knowledge, deepen the students' understanding of the knowledge points and mastery, and enhance the students' understanding and practical ability of scientific modeling. It also promotes students to accumulate modeling metacognition and metamodeling knowledge, deepens students' understanding and mastery of knowledge points, and improves students' understanding and practical ability of scientific modeling. On the other hand, scientific modeling involves the testing and modification of models, teachers should encourage students to think independently and explore independently in the teaching process, promote students' creative thinking, construct diversified modeling schemes, and guide students to verify, reflect and summarize the multiple modeling schemes, and constantly revise the modeling scheme, in the process of finding the optimal modeling scheme, to further enhance students' model testing and modification ability. The students will be guided to verify, reflect and summarize the modeling schemes, and in the process find the optimal modeling scheme, which will further enhance their ability of model checking and correction.

4.2 Constructing an evaluation system for students' modeling ability

Stemming from an interdisciplinary perspective, it is critical to devise assessment methods that focus on scientific model development .Assessment methods are critical to identify learning challenges and determine the best way to support learning. As such, teacher educators need to design and implement strategies to promote(Brennan and Resnick 2012;Grover et al. 2014; Grover and Pea 2013)scientific model development. Thoughtful and systematic assessment that includes formative and summative methods (Brennan and Resnick 2012) is achievable .

Formative assessment offers insights on students' learning processes (Piech et al. 2012) and compensates for potential misleads during summative assessment (Werner et al. 2012). Examples of formative assessment methods that focus on scientific modeling include (a) artifact-based explanations about how coding concepts are employed (Werner et al. 2012) to simulate models, (b) use of computer science and science terminology (Lemke 1990), (c) peer feedback on code (Grover et al. 2014) and scientific model, and (d) documented code construction and debugging strategies to simulate specific aspects of a phenomenon.

The Compulsory Education Science Curriculum Standard (2022 Edition) regards scientific modeling as an important part of scientific thinking and a major component of scientific core literacy, so the teaching of scientific modeling should focus on the assessment of students' modeling ability and build a corresponding evaluation system of scientific modeling ability. First of all, scientific modeling ability cannot be separated from specific disciplinary knowledge and context, and it is difficult to reflect students' real scientific modeling level by generalized assessment, therefore, scientific modeling assessment test questions should be designed based on specific disciplinary content. Therefore, the scientific modeling assessment questions should be designed based on subject-specific content and transformed from a single knowledge point examination to the evaluation of students' higher-order thinking ability. The preparation of assessment questions should be based on the curriculum standards and teaching content, using quantitative scoring scales to reflect students' real scientific modeling level by focusing on scientific modeling indicators such as students' model construction and use, model checking and modification, modeling metacognition and meta-modeling knowledge, and so on. Secondly, teachers should comprehensively use a variety of evaluation methods, such as formative evaluation and summative evaluation, to monitor students' understanding of the model and the modeling process in a timely manner during the teaching and learning process, to examine students' practical ability in scientific modeling, and to improve the modeling teaching practice based on students' assessment results. Through self-evaluation and peer assessment, students can compare, summarize and reflect on the constructed models, find out the strengths and weaknesses in the modeling process, improve their ability to verify and constantly revise the models, better promote students' active self-reflection, develop their thinking and improve their scientific literacy.

4.3 Constructing an intuitive and realistic modeling teaching context

In the teaching of scientific modeling, teachers should take the cultivation of students' practical application ability as the teaching goal, taking into account the training of students' scientific thinking ability, highlighting the ability-based, shifting from knowledge system-centered to task-driven as the core, and giving full play to the nurturing value of science courses. Scientific models are abstract and closely related to real life, so teachers need to use intuitive and contextualized teaching methods in the teaching process.[16] Therefore, teachers need to use intuitive and contextualized teaching methods in the teaching process, so that students can feel the concrete value of scientific modeling in real-life problem situations through specific modeling teaching cases. First of all, teachers should introduce real problem situations in teaching practice and integrate scientific theories in contextualized teaching. For example, when teaching physics, geography and other subjects, they should import from real problems, present abstract subject theories through real situations, build a bridge between theory and practice, cause students to think about real problems, and increase students' knowledge of modeling. Secondly, teachers should encourage students to solve real problems through modeling, guide students to actively observe real-life scientific phenomena, and encourage students to build and use models to explain and illustrate the observed scientific phenomena, and gain a deeper understanding of nature through modeling. For example, students can actively observe the rise and fall of the sun, from which they can learn the model of the sun rising in the east and setting in the west. Scientific modeling is closely related to real life, so it should be integrated into real teaching situations in the teaching and learning of scientific modeling to fully reflect the nurturing value of the science discipline.

4.4Providing a modeling-based scaffolding

Starting in the 2000's, more studies were carried out on modeling processes in practice, and various definitions of modeling processes were proposed as a result. For instance, Justi and Gilbert (2002) presented a diagrammatic representation to depict modeling as a process in which a mental model is produced and expressed in any mode of representation. For Hestenes and Halloun, the use of the modeling approach is apedagogical theory which is concerned with cognitive processes and curriculum. The teacher would discuss the organization of scientific knowledge during each modeling stage, and encourage students to employ modeling strategy when trying to solve problems in textbooks (Hestenes, 1987) or experimental activities (Halloun, 1996). As for Clement, Justi, and Gilbert, modeling is a vigorous tool to develop mental skills. During the modeling processes, researchers identified several steps, such as constructing, validating, applying, evaluating, and revising scientific models during modeling practice (e.g., Hestenes, 1987; Lehrer & Schauble, 2003; Schwarz et al., 2009). Inspired by Hestenes and Halloun's idea proposed the DEAR cyclic model on modeling practice (Chiu, 2016; Chiu, 2018). This DEAR model integrated Justi and Gilbert's consideration of the scope and limitations for a model to construct a circulated process of modeling, that is model Development, model Elaboration, model Application, and model Reconstruction . The aim of our DEAR cycle is to be a goal-oriented and competence-based scaffolding for designing, implementing, or evaluating efficient modeling-based instruction, model-based text (Jong, Chiu, & Chung, 2015), and model-based assessment of students’ products (Chang & Chiu, 2009).The DEAR model does not only include the modeling processes, it has also taken students’ learning outcomes (such as the initial models) into account.

There is an overall consensus in the scientific modeling literature that high-quality scaffolds (e.g., reflection prompts) are critical to support sensemaking about science phenomena and development of scientific models (Chang et al. 2010; D’Angelo et al. 2014; Rutten et al. 2012; Seel 2017; Smetana and Bell 2012; van Joolingen 2015). Scaffolds on scientific model progression guide (a) selection of specific aspects of the phenomenon to be included in a simulation, (b) identification of misconceptions, (c) self-regulation of one’s own learning processes, and (d) reflection on the nature and purpose of models.Scaffolds are also essential to promote mindful code construction and error debugging (Kim et al. 2018;Lewis 2012; Vasconcelos and Kim 2019). In summary, scaffolds are needed to support teachers’ use of scientific modeling lessons that feature simulation coding.

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