Developing students' understanding of scientific models and modeling competence via modeling-based Instruction and innovative technology

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Understanding of nature of models and developing modeling competence in science education have gained a lot of attention in the past two decades. Researchers have emphasized the core elements around models and modeling in building up their conceptual framework and examining the impact of learning outcomes via modeling instruction. Science curriculum standards (such as Next Generation Science Standards, NGSS) also pinpointed the importance and value of cultivating students' modeling competence in school science practices. Taiwan is also aware of this trend in science education and highlighted modeling competence as one of the core competence in learning sciences. A series of studies on understanding nature of models and modeling-based instruction sponsored by Ministry of Science and Technology in Taiwan will be introduced to show the positive impact of modeling-based instruction on chemistry learning. Also, samples of the use of technology (such as Augmented Reality and Virtual Reality, AR/VR) as scaffolds in facilitating and assessing students' visualization of abstract and complex scientific concepts will be discussed.

Keywords: nature of models, modeling, NGSS, AR, VR

Introduction

Scientists use scientific models to describe, explain, communicate, and predict how scientific phenomena behave and change. Their expertise of using scientific models plays important roles on constructing and developing scientific theories, linking evidence with theories, applying theories or hypothesis into problem solving contexts, and judging the validity of the conclusions. Experts, like scientist, take a long period of time to develop such expertise of modeling processes in their scientific fields.

Despite the importance of developing modeling competence in science domains, research pointed out students were not only lacking in correct perceptions about scientific models, but also lacked modeling competence in learning sciences. To enhance students' understanding of the nature of scientific models and modeling processes has thus become an emerging task to accomplish in the new science education reforms (e.g., Next Generation Science Standards, 2013). As National Research Council (2012, p.58) pointed out, the progression of modeling can begin in the earliest grades, starting from concrete "pictures" and/or physical scale models(objects) to more abstract representations of relevant relationships in later grades (such as a diagram representing forces on a particular object in a system).It is evident that engagement in modeling and in critical and evidence-based argumentation invites and encourages students to reflect on the status of their own knowledge, their understanding of how science works, and competence in problem solving. And as they involve themselves in the practices of science and come to appreciate its basic nature, their level of sophistication in understanding how any given practice contributes to the scientific enterprise can continue to develop across all grade levels (NGSS, 2013). Therefore, curricula will need to stress the role of models explicitly and provide students with modeling tools so that students come to value this core practice and develop a level of facility in constructing and applying appropriate models (NGSS, p. 59). The emphasis on modeling is new and will need to be an explicit element of teacher preparation in science education.

Students' perceptions of nature of models

Once Grosslight et al. (1991) investigated novices and experts' conceptions of models, various research has been carried out. Various definitions of models have appeared in these research studies, such as "a model in science is a representation of a phenomenon initially produced for a specific purpose" (Gilbert,

ISBN: 978-602-73192-1-9

Boulter, & Elmer, 2000, p. 11), or"a model may be seen as an exact copy of the original (level I), or the possibility (level II) or necessity (level III) of differences between the model object and the original may be realized" (Upmeierzu Belzen and Krüger, 2010, cited in Krell, Reinisch, & Krüger, 2015). Other researchers claimed models as intermediates between the actions of experiment and scientific theories (Giere, 1991), a bridge sharing similar information between source and target knowledge (Glynn, 1991; Harisson &Treagust, 2000), and "intermediaries between children's capacity of interpreting natural facts and the multiple aspects of these facts that substantially work by representing hidden semantic connections and organizing them in a comprehensive meaning" (Acher, Arca, & Sanmarti, 2007, p. 399).

In the classic work by Grosslight et al. (1991), they interviewed 33 mixed ability seventh grade students, 22 11th grade honors students, and four experts to identify three general-level conceptions of models that corresponded to different epistemological views. They found that about two-thirds of the seventh graders were assigned to pure level 1 modelers that bore a naïve realist epistemology. About 36% of the eleventh graders were identified as pure level 2 modelers. The level 2 modelers began to realize that there was a specific, explicit purpose that mediated the construction of models, and the modeler played a role in modeling. No students from either grade were identified as level 3 or mixed level 2/3 modelers. All four experts emphasized different aspects of models and expressed a constructivist view of models. Kozma (2003) also claimed the differences between the representational skills of expert chemists and novices. Scientists tend to be fluently coordinate features within and across multiple representations for their research while students have difficulty moving across or connecting multiple representations. These representations could be considered as different modes of models of scientific concepts. Crawford and Cullin (2004) studied prospective secondary science teachers' understanding of the models, they found that "a scientific model is a visual learning aid of something in life…", "different models can present the same information in a different way", and etc. However, they also found that there appeared to be no substantial progress made in their intentions to teach *about* models (p.1399). Lin (2014) found that both science-major and non-science major practicing teachers were lacking of knowledge about nature of models and then either responded to the questions with reference to specific models or contained acquiescence bias. Other research also showed evidence that students and teachers did not develop appropriate understanding of scientific models that could have facilitated their learning of sciences (e.g., Levy & Wilensky, 2009; Treagust, et al., 2004).

A triplet framework of understanding of nature of models was proposed (Chiu, 2008). In one of our previous studies, we adopted structure equation modeling with higher-order confirmatory factor analysis of 46 items on 400 senior high school students' perceptions of nature of models from three aspects, namely ontological, epistemological, and methodological perspectives (See Figure 1, Chiu et al. in preparation). The results revealed that in general, the students performed the best on items related to the methodological perspective, followed by items related to the ontological and then epistemological perspectives. The differences were significant. However, the level of understanding of nature of models (NOM)still has a lot of room for improvement.

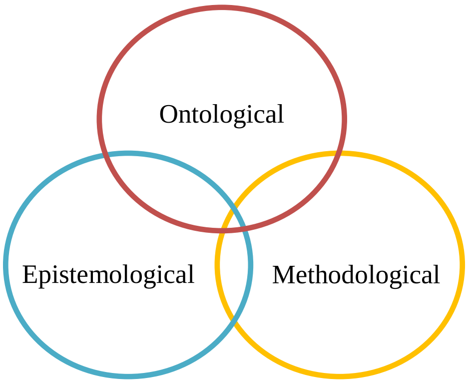

Figure 1. Theoretical framework of nature of models

Developing students' modeling competence

It is a universal phenomenon that school curricula fail to focus on the development of scientific models; textbooks also do not make appropriate use of historical and epistemological models, and teaching was found to rely on hybrid models (e.g., with scientific and alternative models owned by learners) (e.g., Gobert & Pallant, 2004). Models are constructed through modeling, a process of developing concrete representations of abstract ideas in science and the underlying mechanism(s) that causes physical phenomena, and are driven by observations of physical phenomena. Research revealed that students' involvement in the modeling processes could achieve better learning outcome and support effective conceptual understanding of scientific concepts (e.g., Harrison & Treagust, 1996; Schwarz, et al., 2009).

ISBN: 978-602-73192-1-9

Several modeling processes were identified by researchers in the past. For instance, Schwarz et al. (2009) proposed a learning progression which includes two facets, namely 'models as generative tools for predicting and explaining', and 'models change as our understanding improves incorporating the modeling practices and meta-modeling knowledge' (p. 637). Their model has been widely cited and implemented for promoting students' modeling competence in science classroom. Louca (2015, p.193) summarized four phases of modeling process from several studies, the four steps are: (1) making systematic observations and/or collecting experiences about the phenomenon under study, (2) constructing a model of the phenomenon based on those observations and experiences, (3) evaluating the model against standards of usefulness, predictive poweror explanatory adequacy, and (4) revising the model and applying it in new situations. Among these studies, Halloun (1996, 2007) identified five steps of modeling, which includes model selection, model construction, model verification, model analysis, and model deployment. These steps explicitly stated how to gradually develop modeling practice and appreciate the steps to facilitate the construction of scientific models. After several modifications of Halloun's model, Chiu (2008, 2010, & 2016) developed a modeling framework for promoting modeling competence in which it included four stages, namely model development, model elaboration, model transfer, and model reconstruction. Each stage constituted two steps (See Figure 2). The eight steps were model selection (MS), model construction (MC), model validity (MV), model analysis (MA), model application (MApp), model deployment (MD), model revision (MR), and model transformation (MT). This framework was used in several studies to put theory into practice (e.g., Jong & Chiu, 2013). Two other cases will be discussed below.

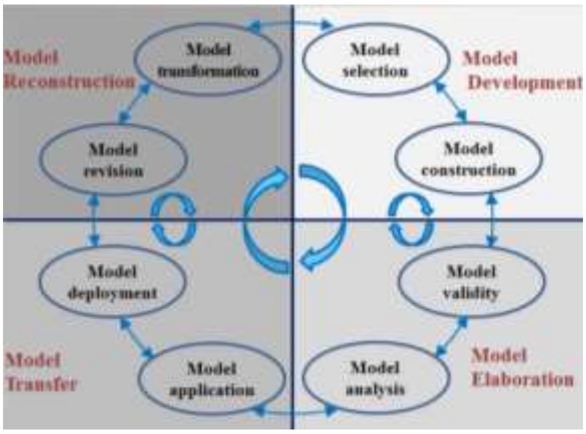

Figure 2. Theoretical framework of this study

Cases of Modeling-Based Instructions

Two cases with the modeling-based text/instruction (MBI) to improve students' modeling competence and understanding of the content knowledge will be introduced in this presentation. To adopt the modeling process model shown in Figure 2, two studies for teaching the topics of electrochemistry were carried out for junior and senior high school students. We found that the students taught with the modeling-based text/instruction outperformed the confirmation inquiry instruction not only in terms of overall performance but also on the higher order thinking of the scientific models system. More importantly, the students in the MBI group outperformed the CI group on overall modeling competence and model construction, and validation sub-modeling competence. The modeling assessment tool was able to identify students' levels of competence in modeling practice. Consistent findings were revealed for both studies.

We found that even with few changes in the textbook (modeling-based text) enabled students to better apply scientific information in the construction of their conceptual knowledge and development of their modeling competence. This encourages us, as science education researchers, to advocate modeling-based text and instruction as capable of allowing students to appreciate the development of understanding the nature of models from ontological, epistemological, and methodological perspectives. The modeling processes can also allow students to generate functional mental models, to solve problems in contexts, and to provide a mechanism of construction and use of models for learning sciences.

AR/VR for promoting and assessing motivation and conceptual understanding

Stereochemistry is one of the challenging topics to be learnt in high school chemistry classrooms. It requires learners to visualize the configurations of atoms of molecules mentally and spatially. Thus, visuospatial skills play important roles in the learning of stereochemistry. However, many students found it difficult to learn organic chemistry because the 2D presentations in textbooks do not carry the spatial arrangements of molecules to help them visualize the complex structure of molecules. Also, the students might not be equipped with the necessary visuospatial skills for learning stereochemistry. Hence, the current trends of augmented reality (AR) and virtual reality (VR) learning have become new learning paradigms in science education. It is not only because of their uniqueness of presenting abstract concepts but also stimulates learners' motivation and interest in learning sciences. For instance, we integrate AR and VR as learning tools that AR allows students to use target cards to visualize the structure of each individual molecule from various perspectives. On the other hand, the VR model allows students to engage in the interactive game that heightens their motivation for learning, and enables assessment of their learning of the core concepts in stereochemistry (See examples in Figure 3). In our lab, we integrated the advantages of AR and VR to create a learning and assessment tool in which organic compounds were embedded in a field and students have to find the correct structures of chemical compounds within the limited time constraints. We found that students' active involvement might indicate the combined advantages of virtual and augmented reality in chemistry education. It has the potential to arouse students' learning motivation and subsequently, improve their learning outcomes.

Figure 3. The snapshot of AR/VR of organic compounds

Concluding Remarks--- Modeling as a learning tools

To successfully implement modeling activities in school science classroom, enhancing students' understanding of the nature of models and the modeling processes and then integrating modeling activities into school practice should be well planned and implemented. From an early grade, students should be asked to use concrete models (such as blocks, diagrams, and maps) as tools to enable them to construct mental models of scientific phenomenon and to express their ideas. As they grow up, young students should be able to make good use of pictorial and graphical representations to test and verify their hypothesis and construct scientific or mathematical models to illustrate the findings of their inquiry tasks.

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Acknowledgements

The studies presented in this presentation were sponsored by the Ministry of Science and Technology in Taiwan (105-2511-S-003 -031 -MY3, 105-2514- S-003 -008).