Knowledge, Practice and Product

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Knowledge, Practice and Product: Developing Preservice Science Teachers' Modelling Competence

Modelling competence can be defined here as mastery with regard to insightful knowledge, the ability to judge model products concerning their purpose, and the ability to reflect on modelling practice. Research in science education identified the value of engaging the learners in the modelling process, actively using models (Chittleborough et al., 2005; Crawford & Cullin, 2004; Gilbert, 2000; 2004). Zu Belzen et al.(2019) also highlighted the necessity to promote teaching interventions that are aimed at developing modelling competence for both teachers and students (p.39). To achieve this, it is essential to support teachers with robust frameworks for teaching and assessment methods that are related to active modelling. This study aims to explore how to develop and enhance learning environments that best assist preservice science teachers in advancing their modelling competence. An empirical study was conducted to answer the following research question: (1) Is there a difference between pre-service science teachers who have been exposed to a modelling-based curriculum (MBC) and in-service science teachers who have not been exposed to MBC, in terms of three components of modelling competence? (2) If so, what are the differences?

Based on previous studies on modelling competence, two widely recognized categories in the theoretical framework are meta-modelling knowledge and modelling practice (Chiu & Lin, 2019; Nicolaou & Constantinou, 2014; Papaevripidou et al., 2014). meta-modelling knowledge is defined as the understanding of models and modelling. Specifically, a person can explicitly describe and reflect on the actual process of modelling and has an epistemological awareness of the nature, types and purpose of models (Schwarz et al., 2009). Modelling practice refers to an ability to employ a model to represent a physical phenomenon, a system, or an object scientifically, by generating models, evaluating models and modifying models (Khan, 2007). Furthermore, Chiu and Lin (2019) proposed a new theoretical category, namely model product. Namdar and Shen (2015) suggested the importance of model products in the framework of modelling competence because the quality of the products in modelling practices can demonstrate students' modelling knowledge and abilities. According to current studies about modelling competence, the modelling competence framework in this paper focuses on constituent components in three broad categories, namely meta-modelling knowledge, modelling practice and modelling product (see Fig.1).

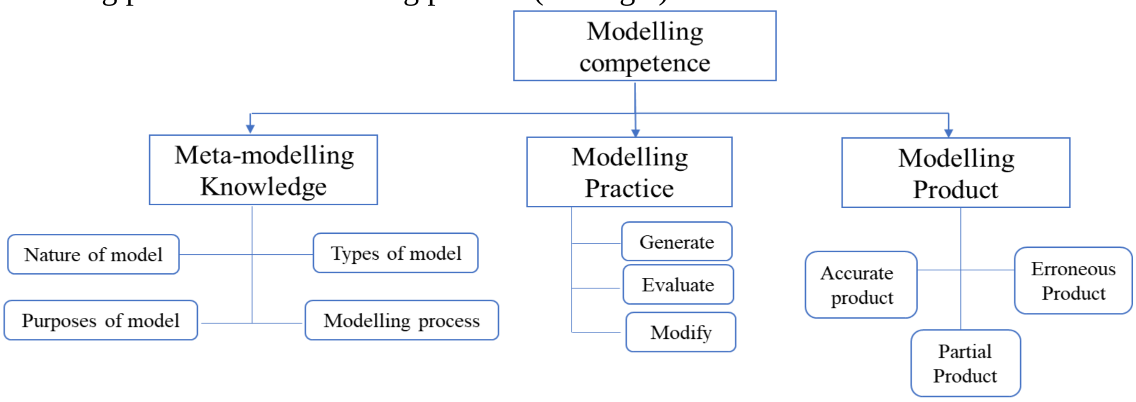

Figure 1. The framework of modelling competence

Method

A quasi-experimental research design was used to investigate the application of the modelling competence framework. The empirical study aimed to develop PSTs' modelling competence through curriculum and instruction and examine the effects of a series of technology-supported model scenarios developed through the curriculum.

Participants and curriculum

This study occurred in a public university in southern China. Purposeful sampling (Patton 2001) was used to select participants, including preservice science teachers (PST) and in-service science teachers (IST). They shared two characteristics: (1) All of them were or had been enrolled in the same teacher education program in the same university providing science curriculum materials and instructional support. (2) They had never experienced modelling training. A total of 76 participants was assigned into two groups: 38 PSTs in the treatment group and 38 ISTs in the comparison group. The intervention participants were exposed to teaching sessions over seven weeks (2.5 hours per week, 17.5 hours in total). For the comparison group, ISTs followed their own schools' schedules to teach children science without any modelling training.

According to prior studies (Schwarz et al., 2007; Kenyon et al., 2011; Soulios & Psillos, 2016), the modelling software used in this study can be classified as theory-building inquiry tools. The intervention was designed in a one-semester pre-service science teachers' methods class, in which the preservice teachers studied and used computer modelling software within modelling-based teaching. The intervention was named as "Modelling Based Curriculum" (MBC). MBC included three core components: (a) incorporating various technology-supported toolkits into science investigations to experience and reflect on how technology can be integrated into science teaching; (b) discussions about technology and modelling tools to provide a rationale and framework for technology integrated with modelling pedagogy; and (c) investigating one of five specific modelling-based theoretical frameworks and technological tools and incorporating them into science teaching. In this study, three types of modelling software were selected, PhET (computer simulation), Scratch (web-based toolkit), and Sagemodeler (web-based toolkit).

Data Sources

Data for this study were collected from two instruments at pre-test and post-test, including a questionnaire with multiple-choice and three open-ended questions.

The questionnaire was designed with 20 items to assess PSTs' meta-knowledge which covered four dimensions: the nature of models (9 items), the purpose of models (10 items), the types of models (9 items) and the process of modelling (7 items). This questionnaire asked participants to rate the items on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). A higher score represented a better understanding of meta-modelling knowledge in terms of each sub-dimension. Three open-ended questions called the Black Box (BB) aimed to assess PSTs modelling practice and product (see Figure 2).

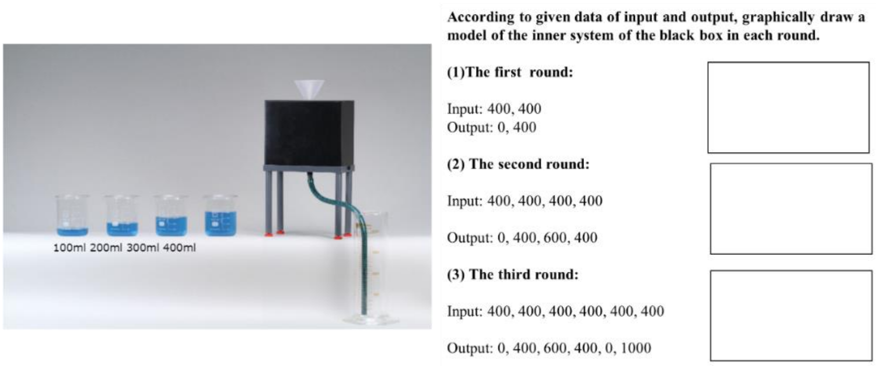

Figure 2. The sample of Black Box

Participants were instructed to think aloud while modelling the black box to gain insight into their modelling processes (Leighton & Gierl, 2007). The quality of the model product was assessed from participants' drawings of the final model of their BB. Participants' think-aloud data was fully transcripted and entered into NVivo for coding. The final drawings were coded by three researchers. One goal of this study was to develop a consistent coding system and interpretation of the quality of students' modelling practice and product. The revised Bloom's taxonomy (Anderson, 2006) and Structure of the Observed Learning Outcome (SOLO) taxonomy (Biggs & Collis, 2014) served as a source for the development of the modelling practice coding system, with four levels: low level, middle level with signal aspects, middle level with multiple aspects, and high level. An example of the assessment rubric of the middle level of modelling practice is presented in Table 1. The final drawing of the BB was graded on a scale of 1– 4, where 1 meant ''the erroneous product,'' 2 meant ''partial product with low quality,'' 3 meant ''partial product with medium quality'', 4 meant "correct product".

The reliability for the meta-modelling questionnaire was 0.84 (internal consistency, Cronbach's α). Inter-rater reliability of the practice and product assessment was determined by two raters. Each rater scored all samples independently. The inter-rater reliability scores of the practice and product were 0.85 and 0.91 (Pearson), respectively. Any inconsistent score was re-evaluated through subsequent discussion.

Table 1. An example of an assessment rubric of the middle level of modelling practice

Level	**Revised Bloom's taxonomy**	**Modelling practice**	**Example**
2 (Middle level)	Apply Analyze	Modellers practice only focuses on **one to two relevant aspects**: **use** the information in a new way**, interpret** the variables /elements, **compare** different sets of data, **distinguish** between the different parts of a system, and **criticize/question** the previous model.	*When I found that the beaker of water poured 200ml into the black box, the previous BB model was obviously not working (Codeuse information and criticize the model).*
3 (Middle level)		Modellers practice only focuses on more than two relevant aspects but they are treated independently and additively.: **use** the information in a new way**, interpret** the variables /elements, **compare** different sets of data, **distinguish** between the different parts of a system, and **criticize/question** the previous model.	Compare: *In the third round of experiments, I found a big difference, that is, when 400ml of water is input for the fifth time, the output of water is the only 0ml. Then I thought of dividing it into two parts, dividing it into two structures on the left and right, and then one structure on the left and one structure on the right (Code-compare, interpret and distinguish the elements of BB).*

Results

MANOVA, using Pillai's trace, was used to check if the two groups' performances of the three components in the pre-test were the same. Results showed that the main effect for two groups was significant ($F\ (3, 64) = 5.41$, $p = .002$, $\eta^2 = 0.20$). The IST group significantly outperformed than PST group on meta-modelling knowledge, but with no significant difference in practice and product. To control for initial differences in the pretest scores of the two groups, ANCOVA was then used, with pretest scores as a covariate. Then paired-samples *t*-tests were used to examine whether PSTs' modelling competence (meta-modelling knowledge, practice and product) improved significantly after MBC. Pearson's correlation was then used to investigate whether any relationship existed between the three components of modelling competence.

Due to space limitations, only partial data results are reported here. All three components in the PST group were higher than in the IST group. The descriptive statistical results are presented in Table 2.

Table 2. Descriptive statistics of three components in the IST and PST group

Component	Group	Mean	Std. Deviation	N
Product	IST	2.84	.51	32
	PST	3.17	.54	29
Practice	IST	2.31	.97	32
	PST	2.90	1.18	29
Meta-modelling knowledge	IST	4.27	.53	32
	PST	4.29	.40	29

Furthermore, there were significant differences among the means of the all dimensions between the two groups in the posttest (Knowledge: $F(2,70) = 4.24$, $p = 0.043$, $\eta^2 = 0.06$; Practice: $F(2,63) = 8.77$, $p = 0.004$, $\eta^2 = 0.126$; Product: $F(2,63) = 10.60$, $p = 0.002$, $\eta^2 = 0.148$). Of final interest was whether meta-modelling knowledge, practice, and product were related. The correlations in Table 3 indicated that participants (PSTs and ISTs) who performed better in practice also produced better products at post-test. However, meta-modelling knowledge was not related to practice and product. The same results appeared in the pre-test.

Table 3. Correlations between meta-modelling knowledge, practice and product

	Meta-modelling	Practice	Product
1 Meta-modelling knowledge	-	-0.142	-0.055
2 Modelling practice	-0.142	-	0.352**
3 Modelling product	-0.055	0.352**	-

** Correlation is significant at the 0.01 level (2-tailed).

Paired-samples t-tests were used for the comparisons of the pretest and posttest scores of each group. Statistically significant differences were found in the PST group (Knowledge, $t(37)=5.323$, $p=0.000$； Practice, $t(28)=2.546$, $p=0.017$; Product, $t(28)=3.780$, $p=0.001$). However, there were no significant differences for all three dimensions in the IST group ($P> 0.05$ in each component). The results were presented in Table 4. These statistical analyses demonstrated that support of a designed modelling-based curriculum in this study effectively enhanced PSTs' meta-modelling knowledge, practice, and the quality of the products they created, but not for the IST group, and this was not because the IST group were already more advanced than the PST group.

Table 4. The Paired Sample *t*-test results: Pre-test and Post-test

		PST Group		IST group	
Components	Test	*t*	*p*	*t*	*p*
Meta-modelling knowledge	Pre-test Post-test	5.323	0.000	1.426	0.163
Practice	Pre-test Post-test	2.546	0.017	0.373	0.711
Product	Pre-test Post-test	3.780	0.001	1.966	0.058

Discussion

From the pretests to the posttests, only the PST group achieved substantial gains in the three components of modelling competence. This was doubtless related to the modelling based curriculum helping the PSTs learn knowledge relating to model and modelling, develop their modelling practice, and conduct more scientific model products. In comparison, in-service teachers with 1-3 years of teaching experience were found to be less competent. The possible reason might be the promotion of modelling competence needs to make sure the intervention approach was easily articulated and understood before others could adopt and implement it. Current studies pointed out that modelling-based instruction is not simple (Justi & Gilbert, 2002; Lopes & Costa, 2007) and teachers often expressed that modelling was a bit ‘‘nebulous’ when they implement the modelling practice into real science classroom (Campbell et al., 2011). On the other hand, Gouvea et al.(2017) also pointed out that science textbooks and the curriculum depict objects or systems as models without making connections to target phenomena or employing them as modelling tools to explore the natural world. As a result, textbook and curriculum content which ISTs are easily approached does not significantly contribute to the development of modelling competence.

In addition, this study suggests revisions in the current theoretical framework of modelling competence. A developed and validated assessment of practice and product could yield a richer and more accurate description of preservice teachers' development. It is worth mentioning that this study added a new component (model product). Modelling product is critical because it makes learner's thinking visible, and teachers can help students monitor how their thinking changes in response to new evidence. Science is a process of constructing predictive conceptual models. The results showed a positive relationship between practice and product, but no relation between knowledge and the other dimensions, which implies practice is more important than knowledge for creating a more qualified model.

Scholars have contended that the understanding of scientific models is an essential factor that influences students' modelling performance (Nicolaou & Constantinou, 2014; Schwarz et al., 2012). However, this empirical study revealed the disconnect between PSTs' understanding of meta-modelling knowledge and their modelling practice as well as the final constructed product. The associated factor with the final product is modelling practice rather than knowledge of the model. This study contributes to narrowing the gap of no empirical studies for the relationship among knowledge, modelling practices and product.

The small sample size was a limitation of this study. In addition, the instruments may not measure individual ability due to the context of the instruments, since the background of participants, both PSTs and ISTs are from chemistry, while the context assessment tends to focus on physics. Future research is needed to develop a validated assessment that can investigate the interaction between the three components on a large scale.

Conclusion

This study developed design principles for enhancing PSTs' modelling competence that has emerged from a revised theoretical framework. To answer the research requestions, two key findings from the study are that: (1) A technology-supported model scenarios benefit the enhancement of preservice teachers' modelling competence more than the teachers who are exposed in the real classroom environment with textbook and curriculum context. (2) Modelling practice is more important than meta-modelling knowledge to conduct qualified model products as the quality of model products is highly associated with modelling practice rather than knowledge.

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