Pre-service Science Teachers' Modelling-strategies

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Background

People in modern societies are faced with copious amounts of information about science and technology. As an aspect of scientific literacy, it is essential for students to learn scientific practices as well as to develop a basic understanding about the nature of science (NGSS Lead States, 2013). The shift to scientific practices, as highlighted in the *Next Generation Science Standards*, implies changes in science teacher education programs as well (Bybee, 2014). For example, when focusing on models and modelling, pre-service science teachers need to develop an elaborate meta-modelling knowledge in order to reflect and discuss about models and modelling in their classes (learning about science), and they need modelling skills in order to guide and monitor modelling practices of their students (doing science; Krell & Krüger, 2016; Hodson, 2014; Oh & Oh, 2011). Scientific modelling can be regarded as an iterative process of developing models as representations of knowledge and assumptions (model of sth.) and of further evaluating these models (model for sth.; Fig.1). The strategy of scientific modelling 'is to gain understanding of a complex real-world system via an understanding of simpler, hypothetical system that resembles it in relevant respects' (Godfrey-Smith, 2006, p.726).

Most studies propose that science teachers' meta-modelling knowledge is rather limited (e.g., Krell & Krüger, 2016; Justi & Gilbert, 2003); most science teachers seem to understand models as representations (model of sth.) but do not recognize their function as research tools (model for sth.). Consequently, models seem to be primarily applied in science lessons as media to describe and to explain something (*expressive modelling*) but are seldom developed, evaluated and modified (*cyclic modelling*; Campbell et al., 2015).

Therefore, there is the need for approaches which provide 'coherent connections between theoretical understanding of modeling, the assessment of instruments and the interpretation of the evidence' to allow 'more powerful feedback for scaffolding learning' (Nicolaou & Constantinou, 2014, p.71). Since most related research in science education follows a quantitative methodology and is product-oriented (Nicolaou & Constantinou, 2014), qualitative studies analyzing pre-service science teachers' modelling-strategies are needed. Such research may enhance programs for science teacher education (Clement & Williams, 2013) and may contribute to theory development in science education research (Nicolaou & Constantinou, 2014). For example, the analysis of the relationship between modelling-strategies and meta-modelling knowledge is seen as 'one of the most pressing needs for future research' (Louca & Zacharia, 2012, p.486). This study contributes to these issues by addressing the following research questions (RQ):

RQ1: Which modelling-strategies can be inferred from pre-service science teachers' modelling-activities? Hypothesis: Based on the findings sketched out above (e.g., Campbell et al., 2015; Justi & Gilbert, 2003), expressive modelling-strategies are expected to be foremost found.

RQ2: To what extent is there a coherent relationship between pre-service science teachers' meta-modelling knowledge and their modelling-strategies? Hypothesis: Since it is assumed that meta-modelling knowledge guides the modelling practice (e.g., Schwarz et al., 2009), a coherent relationship between meta-modelling knowledge and modelling-strategies is expected.

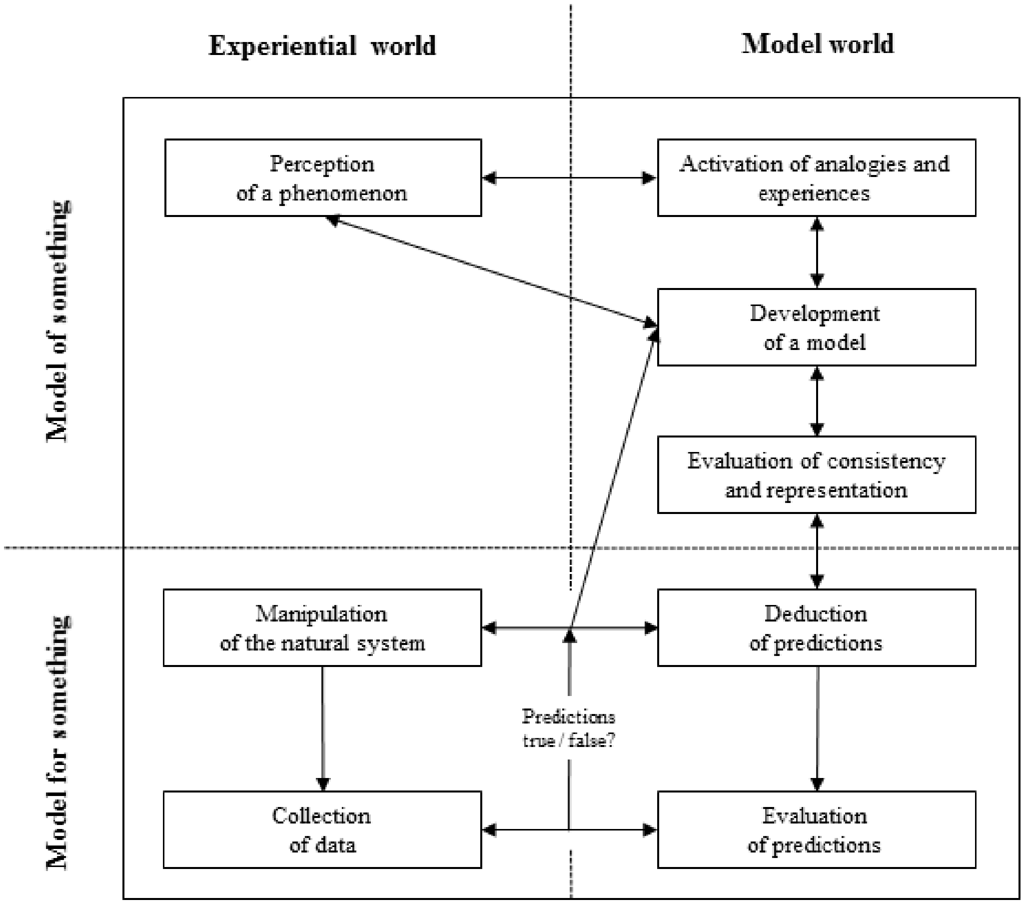

Figure 1. Diagram illustrating the process of scientific modelling (cf. Clement, 1989; Giere et al., 2006; Passmore et al., 2014)

Design

In order to get pre-service science teachers engaged in scientific modelling, a black-box activity is used in this study (Lederman & Abd-El-Khalick, 2002). More precisely, a water black-box is used which is literally a black box with a funnel on its top to fill in water. As a consequence of the arrangement of the inner system of tanks and overflow pipes, and depending on the input, a specific output flows out through a pipe at the bottom of the box (Koch, Krell, & Krüger, 2015). The task for the subjects participating in this study is to graphically develop a model of the inner system of the black-box. In addition, the subjects are asked to think aloud (Ericsson & Simon, 1998). The performances were audio- and video-taped, the verbalizations were fully transcribed.

The data is analyzed within the methodological framework of qualitative content analysis (Schreier, 2012). For this purpose, a category system has been developed based on the theoretical conception of scientific modelling (Fig.1). This deductive approach was supplemented by an inductive refinement of the categories to fully cover subjects' modelling-activities and, by doing so, to ensure the category system's empirical validity (Schreier, 2012). The resulting category system which is used for data analysis in this study includes 19 (sub-) categories (Tab.1).

Table 1. *Category system (M: Model)*

No	Category (Activity)	Sub-Category
1	Perception of a phenomenon	---
2	Exploration of the system	Input/ output (exploratory)
3		Summarizing/ describing observations
4		Input/ output (pattern detection)
5		Recognizing pattern
6	Activation of analogies and experiences	---
7	Development of M	Graphically develop M
8		Change M to optimize consistency (M object)
9		Change M to optimize representation (M of sth.)
10		Reject M due to poor consistency/ representation
11	Evaluation of consistency and representation	Evaluate consistency (M object)
12		Evaluate representation (M of sth.)
13	Finding of consistency and representation	---
14	Deduction of predictions	---
15	Evaluation of predictions	Input/ output (to test predictions)
16		Confirmation of prediction
17		Falsification of prediction
18	Modification/ rejection of M	Change M due to falsified predictions (M for sth.)
19		Reject M due to falsified predictions (M for sth.)

Note: The complete category system additionally includes further explanation and empirical evidence for each (sub-) category. These are excluded here due to space limitations.

Sample and Data Analysis

As yet, four prospective science teachers voluntarily agreed to take part in this study. Three of them studying biology and chemistry, one studying biology and food sciences. Data was collected individually for each subject. First of all, each subject was asked to answer a questionnaire with five constructed response items assessing meta-modelling knowledge (Krell & Krüger, 2016). Thereafter, he/she was introduced to the black-box activity and the method of thinking aloud. Finally, the subject entered a separate room, were he/she had the opportunity to discover the black-box (i.e., fill in water and observe the output) and was asked to graphically develop a model. No time constraint was given.

To discuss RQ1, the subjects' activities are coded by applying the developed category system (Tab.1). Based on a process-analysis of the performed activities, individual modelling-strategies are inferred. To discuss RQ2, the subjects' answers to the constructed response items are analyzed using a coding scheme (Krell & Krüger, 2016) which allows to decide whether the answers reflect an understanding of models as research tools. Both analyses are performed independently by two researchers, Cohen's K is calculated as an indicator of interrater agreement.

Findings

Here we present data of one case ('Marc'; Tab.2). The analysis of Marc's activities resulted in a 'good' interrater agreement (K=0.61). As illustrated in the codeline (Fig.2), the process-analysis reveals that Marc mainly operates in three phases: (1) an exploration phase (27 min), (2) a phase of model development and evaluation (52 min), and (3) another exploration phase (35 min). In phase (1), Marc explores the behavior of the black-box. In phase (2), he performs a sequential development of models. After having developed a model, he mostly evaluates its explanatory power by retrospectively comparing the observations made with the assumed behavior of the respective model (category no.12: *evaluate representation*; Tab.1). This leads to the rejection of various models. During this phase, Marc summarizes his observations several times (category no.03: *summarizing/ describing observations*; Tab.1) and verbalizes difficulties in understanding his observations (category no.01: *perception of a phenomenon*; Tab.1). Phase (3) is once again exploratory and aims at replicating the previously observed behavior of the black-box.

The application of the category system leads to the description of Marc's modelling-strategy as *expressive modelling* (cf. Campbell et al., 2015) since Marc focuses on developing a model which has the power to retrospectively explain his observations (model of sth.) but he does not test the model by deducing and testing predictions (model for sth.).

Table 2. *Findings*

Alias	**Modelling-strategy**	**Meta-modelling knowledge**
Marc	Expressive modelling	Advanced
Kim	Unsystematic modelling	Advanced
Julia	Cyclic modelling	Intermediate
Melanie	*analysis in progress*	Intermediate

The analysis of the constructed response items (K=0.67; 'good') reveals a rather sophisticated meta-modelling knowledge. For example, Marc states that models may be used to deduce predictions and that models may be tested by testing these predictions. Thus, Marc seems to recognize the function of models as research tools (model for sth.).

Summarizing, the findings related to RQ1 are in line with what was expected (e.g., Campbell et al., 2015; Justi & Gilbert, 2003). However, although Marc shows an understanding of models as research tools (Krell & Krüger, 2016; Passmore et al., 2014), he does not perform in accordance with this view. When additionally taking the other cases (Tab.2) into account, there seems to be no coherent relationship between meta-modelling knowledge and modelling-strategies (RQ2). This finding questions the assumption that meta-modelling knowledge guides the modelling practice (Schwarz et al., 2009). However, the inconsistency between performance and meta-modelling knowledge may also be caused by motivational problems, since the development of an explanatory model is quite time-consuming (Fig.2). In addition, this study so far is a case-study and does not allow to generalize the findings. Until NARST conference 2017, the sample will be enlarged and data analysis will be completed.

Significance & Contribution

The development of an elaborate meta-modelling knowledge and modelling skills is seen as important for pre-service science teachers (Krell & Krüger, 2016; Oh & Oh, 2011) in order to meet the demands implied by the shift to scientific practices (Bybee, 2014; Hodson, 2014; NGSS Lead States, 2013). However, most studies about pre-service science teachers' modelling abilities focus on meta-modelling knowledge (Nicolaou & Constantinou, 2014). Thus, there is the need for qualitative process-analyses of pre-service science teachers' modelling-strategies. The present study provides research whose significance arises from at least two perspectives: First, the qualitative description of the way science teachers engage in modelling fills a gap in science education research (Nicolaou & Constantinou, 2014) and allows to address further research questions concerning, for example, the relationship between modelling-strategies and meta-modelling knowledge (Louca & Zacharia, 2012). Second, knowledge about typical modelling-strategies may be used in science teacher education programs by contrasting pre-service teachers' strategies with theoretical descriptions of the modelling process (Clement & Williams, 2013; Nicolaou & Constantinou, 2014).

At NARST conference 2017, we will present the category system as a methodical approach to analyze modelling-activities and to infer underlying modelling-strategies. Further, both research questions will be discussed based on an enlarged sample.

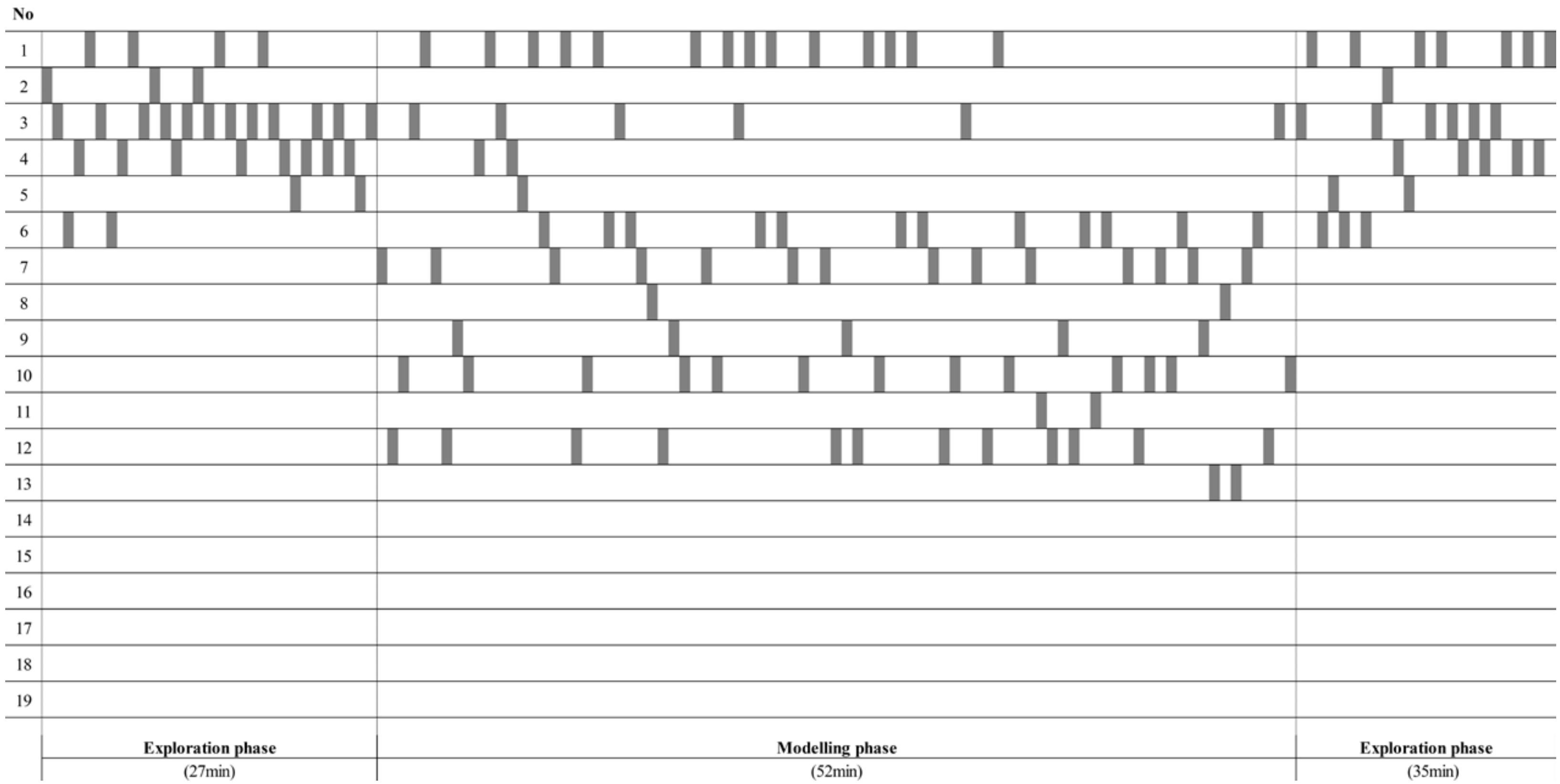

Figure 2. The codeline illustrates the sequence of activities. Note that the filled squares relate to coding units (i.e., activities) and not to a standardized amount of time. See Table 1 for the names of the activities no.1 to no.19.

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