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Learning through modelling in science: Reflections by pre-service teachers

Abstract

This study analyses pre-service science teachers' (PSTs') experiences of working with models and modelling and their ideas about their usefulness in science education. Although several studies have investigated pre- and in-service teachers' views on models and modelling, research is lacking in the Norwegian context. This study addresses this gap by exposing PSTs to a one-day course on modelling in chemistry and exploring their ideas through focus-group interviews. We found that teaching using modelling-related activities promoted PSTs' understanding of models and modelling, especially relating to the scope and limitations of models. Additionally, the PSTs increased their understanding of why such learning activities are important and how to incorporate them while teaching science. Norwegian PSTs responded positively to modelling-based teaching, which seemed to promote metacognition and critical thinking. Therefore, modelling-based teaching could be an effective tool for educating science teachers in how to promote such skills in their classrooms.

Introduction

The use of models and modelling in science education has attracted increased research attention over the last 20 years, including modelling competence in pre-service science teacher education (e.g. Krell et al., 2019; Gilbert & Justi, 2016). Modelling is linked to teaching skills seen as being essential for 21st-century citizens, which are metacognitive skills, critical- and creative-thinking skills and learning to learn (OECD, 2019; Pellegrino & Hilton, 2012). Therefore, modelling-based teaching, where pupils create their own models, could be a way to promote pupils' competence and establish creative learning environments.

A key element in the Norwegian science curriculum, LK20, is ‘scientific practices’, which calls for pupils to develop their joy of creating, their ability to think originally and their understanding of scientific theory by making models themselves — that is, by modelling (Norwegian Directorate for Education and Training [NDET], 2019). This shift in emphasis places new demands on science teachers. Yet, to date, little is known about Norwegian pre- and in-service teachers’ experiences with, as well as their views on, models and modelling. Therefore, this study investigates modelling-based teaching in science teacher education in Norway.

Models and modelling are explicitly included in influential curricula around the world (e.g. NGSS Lead States, 2013) and now also in Norway. LK20 includes a progression in modelling competence as pupils get older (NDET, 2019). Younger pupils are required to compare models to observations and discuss why models are used in science, whereas older pupils are required to create and evaluate models, use them for scientific predictions and understand their strengths and limitations. Modelling is new to the Norwegian curriculum and provides a link between learning discipline-specific knowledge and practicing skills, such as critical thinking (OECD, 2019). Until now, an explicit focus on the limitations of scientific models has been absent from the Norwegian science curriculum, including for upper secondary chemistry (Vesterinen et al., 2009).

Pellegrino and Hilton (2012) recommend developing instructional programmes that use multiple and varied representations of concepts and tasks, encourage elaboration, questioning and explanation, engage learners in challenging tasks, teach with examples and cases, prime student motivation and use formative assessment. The use of models in science promotes the national curriculum’s overarching goal of using a broad repertoire of learning activities to create motivation and enjoyment among pupils (NDET, 2017).

Aim of the study

The enhanced focus on models and modelling in school science makes it important to explore the views that teachers and pre-service teachers (PSTs) have on this topic. Modelling competence and the use of representations are essential to scientific literacy, and teachers’ knowledge and use of models and modelling are becoming increasingly important (Chiu & Lin, 2019; Knain et al., 2017). PSTs’ understanding of models and modelling has previously been found lacking in several studies. The PSTs are the ones who will eventually implement modelling in schools, although they consider their limited knowledge as a challenge in this context (Aktan, 2016). In this study, we exposed two classes of PSTs to a one-day course on modelling in chemistry as an example of exemplary teaching, in which the students take on the role of the pupils. Through focus-group interviews, we investigated the PSTs’ experiences of working with models and modelling in this exemplary fashion as well as their views on the role these models have in teaching science.

Our study aims to illuminate Norwegian PSTs’ ideas about model- and modelling-based teaching and their experience of working with models and modelling in science teacher education. To this end, we investigate the following research questions:

RQ1: How do pre-service teachers experience working with models and modelling?
RQ2: What are the pre-service teachers’ ideas about the role and usefulness of models and modelling in school science?

Models and modelling in science education

Even though no unique definition of a model exists, it is commonly thought of as a representation of something (Oh & Oh, 2011). In this paper, we subscribe to the ‘artefactual view’ of models (Gilbert & Justi, 2016). In this view, models are human-made artefacts representing a target system, which includes theoretical or abstract entities. Drawings, digital and gestural representations as well as mathematical equations are included in this view of models. The target is the object, phenomenon, process or idea that is modelled.

The common core practices of modelling in education are the creation, evaluation and revision of models (Clement, 1989, 1993a, 1993b; Gilbert & Justi, 2016; Halloun, 2007). The creation process involves using one or more external modes of representation, for example, drawings, concrete three-dimensional (3D) artefacts or mathematical formulas. Evaluating a model may include investigating to what degree it succeeds in its purpose as well as assessing whether the model can be improved and determining its scope and limitations (Gilbert & Justi, 2016; Justi, 2009, 2013; Williams & Clement, 2015). Revising a model means changing it, usually according to either the evaluations done by the modeller or the feedback received from a third party.

In a position paper on modelling competence in science education, Chiu and Lin (2019) state that the development of modelling competence is essential to scientific literacy for 21st-century citizens and that a modelling-based scaffolding framework can provide an authentic learning experience and enhance students' engagement in scientific practice. Emphasising the connection between subject knowledge, education strategies and practice in teacher education has been found to aid PSTs in including teaching strategies learnt on campus in their own teaching (Olufsen, Karlsen and Ødegaard, 2017).

In an overview of the nature of models and their uses in the science classroom, Oh and Oh (2011) conclude that there are five aspects of models that science teachers should know. The first is the meaning of a model. A model is not a mere copy or replica but a representation of a target that may include objects but also phenomena, processes, ideas and their systems. The model may also act as a bridge between theory and a natural phenomenon. The second is the purposes of modelling in science as a device for thinking and communicating. The model helps communication, since it simplifies or visualises a process, making complex phenomena more accessible. The third aspect is the multiplicity of scientific models, meaning several valid models may be constructed for the same target that may relate different aspects or features and have different limitations. The fourth aspect is the change in scientific models; they are revised as scientific knowledge progresses. The final aspect is the use of models in science classrooms, where the use of multiple representations for the same phenomenon is important for student learning. Additionally, models can be included in the classroom by allowing the pupils to create, test and revise them.

Oh and Oh (2011) suggest a pedagogical transformation in science education — one that focuses on the thinking and practical skills involved in producing scientific models as well as their content. Such a transformation would also include taking advantage of Joolingens' (2004) modelling activities, in which models are used to help students to express ideas and ask questions and students are taught to compare and assess these models in order to improve them in a cyclic manner.

Recent research concerning pre-service and in-service science teachers' experiences with using models and modelling

Many studies have investigated teachers' knowledge and use of models and modelling. As curricula around the world begin to further emphasise the development of 21st-century skills, this topic has become increasingly more relevant, yet it still requires much research (Chiu & Lin, 2019). Some of the latest research related to models and modelling in teacher education will be summarised here.

PSTs have been found to hold naïve and simplistic views of models as only copies or replicas (Danusso et al., 2010; Soulios & Psillos, 2016; Torres & Vasconcelos, 2017; Yenilmez Turkoglu & Oztekin, 2016). This naïve understanding is even evident for PSTs holding degrees in physics, engineering and mathematics (Danusso et al., 2010). Previous intervention studies have shown that model- and modelling-oriented teaching plans have helped students to attain a more nuanced view of models (Danusso et al., 2010; Soulios & Psillos, 2016; Torres & Vasconcelos, 2017); and some have suggested a stronger focus on the components of scientific models in teacher education (Danusso et al., 2010).

A Danish study showed that in-service teachers thought it was important to teach meta-knowledge about models to pupils but that more experienced teachers tended to be more focused on modelling processes in their teaching than less experienced ones (Nielsen & Nielsen, 2019). After participating in modelling interventions, PSTs also saw a greater need for meta-modelling knowledge for their pupils, such as the limitations of models and their use in science (Torres & Vasconcelos, 2017). These results suggest the importance of including scientific modelling in science teacher education for PSTs with or without previous degrees in science (Danusso et al., 2010) as well as for in-service teachers (Nielsen & Nielsen, 2019). Nielsen and Nielsen (2019) argue that teacher educators should extend teachers' modelling practices by building on already well-established practices to make them more process oriented.

Studies have shown that teachers describe models as artefacts for recalling and remembering content knowledge and as tools for simplifying, generalising and highlighting content (Aktan, 2016; Nielsen & Nielsen, 2019; Yenilmez Turkoglu & Oztekin, 2016). A desire to promote content knowledge from the curriculum rather than meta-knowledge about models can cause teachers to be more product-oriented rather than process-oriented (Nielsen & Nielsen, 2019).

PSTs perceive a lack of modelling experience and limited knowledge about models as challenges to adopting a modelling-oriented practice (Aktan, 2016). In-service teachers note that models can be used to assess pupils' content knowledge but that the assessment of modelling work can be challenging (Nielsen & Nielsen, 2019). However, several studies show that PSTs believe models and modelling can prompt interest and creativity among pupils and can make the teaching more diverse, accessible and concrete (Aktan, 2016; Nielsen & Nielsen, 2019; Torres & Vasconcelos, 2017; Yenilmez Turkoglu & Oztekin, 2016). Additionally, models can provide a concrete reference point for the subject under study (Nielsen & Nielsen, 2019) and can improve pupils' reasoning and arguing skills (Ryu et al., 2018; Torres & Vasconcelos, 2017).

METHODS

Study participants

This study follows a qualitative approach and was conducted in connection with a one-day course on models and modelling in chemistry. The participants were PSTs at one of Norway's largest teacher education institutions and were studying to become teachers for grades 1–10. The PSTs were from two classes in their fourth and final year of teacher education and had chosen science as their specialisation for that year. The study was conducted at the beginning of their science course. There were no science prerequisites for the course, and the PSTs were not familiar with chromatography, which was the topic of the course. All PSTs were invited to participate in the non-mandatory course as part of their science education, regardless of their participation in this study. An overview of the number of participants is given in table 1.

Table 1: Overview of study participants. Groups A and B had their courses on different days. Students partaking in the course but not in the research study are not included in the table.

Group A	**Male**	**Female**	**Total**
Partaking in the course	3	4	**7**
Partaking in the interview	3	4	**7**
Group B	**Male**	**Female**	**Total**
Partaking in the course	7	5	**12**
Partaking in the interview	3	3	**6**

Teaching plan

The PSTs took part in different learning activities related to paper chromatography, shown to the left in figure 1, for which they constructed models. Before the PSTs arrived, the teacher educator had prepared filter papers for the chromatography experiment. Lines had been drawn using three different watercolour markers (yellow, red and blue) painted on top of each other to make an apparent brown line. The PSTs immersed one end of the paper in water and observed the colours separating as the absorbed water extended through the line. Based on these observations and their knowledge about pure substances and mixtures, the PSTs were instructed to create so-called nano-models for the process they had observed. The term 'nano-model' indicated that the model should be on a molecular level. The criteria for the nano-models were that they should show and explain the observations: The water moves upwards, the colours travel upwards and some colours travel farther than others. The nano-models and the set of criteria were revised twice during the day, and examples of three successive nano-models are shown in figure 1. The PSTs evaluated their own as well as other models for the system before revising their nano-models.

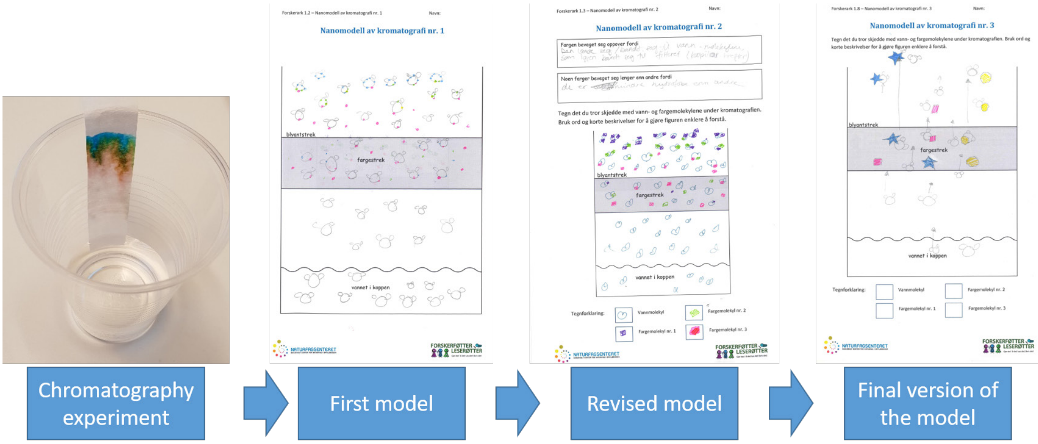

Figure 1: Picture of the chromatography studied by the pre-service teachers (PSTs) and an example of one PSTs' models for chromatography.

Figure 2 presents a schematic overview of the modelling-related activities the PSTs performed during the day. The nano-models created by the PSTs were drawn on paper into an existing template showing a glass of water and a strip of paper. The teacher educator presented the PSTs with two 3D models for mixtures and chromatography, called the pasta model and the fan model, respectively. The pasta model is a model of mixtures and pure substances, and it was presented before their first nano-model was created. Here, the molecules of different pure substances were represented by different types of pasta. The fan model was presented to the PSTs before they revised their own nano-models for the first time. This model shows the separation of molecules by using a fan, and it represents different molecules as objects that are transported differently by the wind.

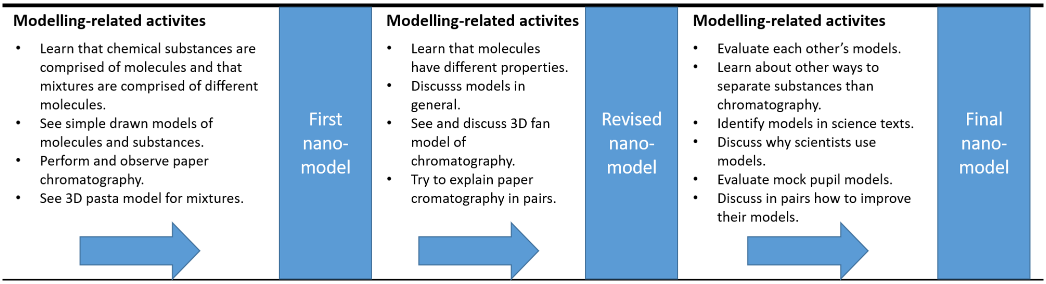

Figure 2: Schematic overview of the modelling-related activities performed by the pre-service teachers.

Before making their final revision, the PSTs were asked to evaluate the nano-models in pairs, starting with one another's models and moving on to some mock pupil models. When evaluating one another's nano-models, the PSTs were instructed to ask questions like 'How does this model show…?' related to the above-mentioned criteria. The mock pupil models were nano-models for the same experiment drawn on the same template as the ones the PSTs were making themselves. Facts about the properties of molecules being static (the molecules do not change during the experiment) were presented along with these models. The PSTs were asked to evaluate the mock pupil models by answering questions like 'Does the model explain…?' with various aspects of the experiment inserted, and finally 'Is this model consistent with what we know about molecules?' The teaching plan is available from the Norwegian Centre for Science Education (n.d.) and was originally designed for children aged 10–12.

Data collection

At the end of the course, the PSTs were invited to participate in focus-group interviews (Bryman, 2016). These interviews were conducted using a semi-structured interview guide (Appendix A) developed for this study (Bryman, 2016). There were questions about how the PSTs experienced working with models and modelling, what they thought about using models and modelling in their future work as teachers and their perceptions of them in general. The interviews were recorded with the participants' consent using video recordings and backup sound recordings. The audio from the videos was transcribed for further analysis. The video images were only used to determine which person was talking. Additionally, the conversations the PSTs had while evaluating models were audio-recorded, and the models produced by the PSTs were collected. The empirical data used in this paper consists solely of the interview transcripts. The study was approved by the Norwegian Centre for Research Data (NSD).

The researchers are teachers in teacher education in Norway, and the course on modelling in chemistry was taught by one of the researchers. This researcher was the regular chemistry teacher for one of the two groups of PSTs (A). To enable the participants to speak more freely and to encourage more elaborate descriptions, the interviews were conducted by the other researcher. This researcher was the physics teacher for the other group of PSTs (B). As the researchers were teachers, this may have influenced the data. However, there were no significant differences in the data from the two groups, thus indicating that this did not influence the outcome of the study.

Analyses

The transcribed interviews were analysed using a thematic analytical approach (Braun & Clarke, 2006). The transcriptions were read several times and coded inductively by both researchers. To ensure consistency, the authors independently coded the same interview and compared codes to make sure they were interpreted in the same way. Descriptions for all the codes were written down and agreed upon. The codes were later grouped into two themes with three sub-themes each. All the codes, themes and sub-themes were established and continuously refined through dialogue between the authors throughout the process, with input from a third research colleague.

Quotes from the interviews are presented, and they have been translated into English in a way that preserves the original intention, as the interviews were conducted in Norwegian. Small words and stuttering were excluded, as these were not considered in the analysis and would be difficult to translate. Original quotes with the translations can be found in Appendix B.

FINDINGS

Two themes emerged from the discussions in the interviews each relating to one of the research questions. We present the findings grouped under these themes.

PSTs experiences working with models and modelling (RQ1)

One theme that emerged from the analysis was the participants' experiences of working with models and modelling. The related sub-themes were the challenges, opportunities and relevance of modelling-based teaching in science teacher education.

Challenges related to modelling-based teaching

The PSTs encountered several challenges during the day of modelling-based teaching. Their lack of experience with scientific modelling made the task at hand unclear and a lack of relevant subject knowledge made them feel insecure. The PSTs' first nano-model was based on little to no knowledge about the target or modelling experience, to which they reacted differently. Some experienced the lack of knowledge as freeing, making the task easy, as they saw no real requirements.

Other PSTs experienced this lack of knowledge as challenging and frustrating, as they did not know what their nano-model should look like or how to best express it. Some drew the macroscopic result of the paper chromatography as their first nano-model, and some revealed that they had ignored or not grasped the instructions about making legends and other criteria for the first two versions of their nano-models. Several PSTs mentioned this problem and blamed their lack of scientific knowledge and inexperience with modelling. Discovering how to represent elements, use legends and illustrate progress was difficult, although there is no doubt that the PSTs had been repeatedly exposed to similar models during their 16 years in the Norwegian school system. As a solution to the difficulty of performing the first modelling task, one PST suggested that pupils should be allowed to discuss how to make their first nano-model with a learning partner.

The questions introduced as scaffolding during the evaluation of the models were an important support mechanism for the PSTs. One PST noted that without these questions, she felt she would have been at a standstill when going from the first nano-model to the second because she was happy with the first one:

> *I felt that the first revision was very similar to the first one I made because we weren't really introduced to any new criteria. At least not to my knowledge. I was pretty happy with how my first model turned out, so I was like, 'Okay, well, let's try a different approach', which I did. But as soon as we got those criteria [evaluation questions], I felt that it got more challenging. But, also, I got a much, much better model out of it because now I knew what to convey with the model. – A2*

Some PSTs said that using these questions made the final revision easier, as they knew better what to convey, which made the task clearer. Others said the questions made it more difficult because they felt restricted by them, although they felt they made their models better. When the task at hand was clearer, the requirements for the nano-models were perceived to be higher, thus making the task more difficult. The PSTs had learnt a lot but did not feel able to produce satisfactory nano-models now that they had more knowledge. It can be easier to see what is wrong than to know how to do something right.

The PSTs described feeling insecure about having to model something without knowing the correct answer and they had concerns about wasting time by working this way. Clearly, they were not used to learning in a setting where the correct answer was either unknown or did not exist, at least in science education. When evaluating models, a lack of knowledge about the target posed a challenge, but, again, the questions helped. Several PSTs pointed out how the questions were phrased to evaluate how the model conveyed various aspects of the phenomenon and not to what extent the models were correct. Such questions could be answered despite lacking the scientific knowledge of the target because the PSTs had made observations that should be displayed by the nano-models. The PSTs realised that modelling activities could be performed without having a correct answer regarding what the model should look like, although they seemed to strongly believe that this correct answer existed and felt frustrated that it was kept from them.

Opportunities related to modelling-based teaching

Several opportunities afforded by modelling-based teaching were uncovered in the interviews. They were mainly related to motivation, meta-reflection and increased modelling competence. Some were directly expressed by the PSTs; others were implied by their discussions.

The PSTs described the opportunity to revisit and modify their nano-model as motivating. One PST called it especially motivating to be challenged with modelling a phenomenon one had observed oneself rather than simply reading about it in a textbook. This statement highlights the importance of having a personal connection to the phenomenon being modelled.

Making nano-models allowed the PSTs to reflect on their knowledge of the modelling target, as expressed in the following quote:

> *You get an overview of what you understand and what you don't understand, in a way. At least that's what I realised when we were working on our final model. Have I really understood this at all? Or what knowledge do I have and what knowledge am I missing? – A3*

This form of self-assessment appears to create an authentic learning demand through modelling. Several PSTs attributed this process to the act of evaluating the models of others more so than their own. This finding might imply that the PSTs felt a stronger authentic desire for subject knowledge when evaluating the nano-models of others than when making their own initial nano-models.

Seeing different models for the same phenomenon and comparing them made the PSTs think about the models in a deeper way. They asked about what makes a model good and thought about what they could and could not infer from a model and the importance of recognising its strengths and weaknesses. This increased awareness of the scope and limitations of the models reveals an increased understanding of their nature.

Being exposed to different models, such as the pasta model and fan model, in addition to the nano-models, also gave the PSTs more knowledge and experience to draw from when making their final nano-model, which was another way in which their modelling competence increased throughout the day.

In general, the PSTs showed great interest in evaluating the models. One main finding was that evaluating other people's nano-models made the PSTs more critical towards their own. One PST described this in relation to having her model evaluated by someone else in her presence. She realised that other people did not have access to her thoughts when she made the model, and, thus, they might interpret the model differently:

> *When you draw your own thoughts, you know exactly what you mean by what you are drawing. But when you switch with someone else, you realise that, yeah, maybe it wasn't that easy. It makes you more aware of where the model needs to be more explicit. – A1*

While evaluating each other's nano-models, the PSTs could inquire when something was unclear, and the modeller could explain their thoughts when modelling. This was not the case when evaluating the mock pupil nano-models, and one PST noted how evaluating those models was especially successful at making one more critical of one's own models because one had to evaluate the model on its own terms. Their reflections on the communicative aspects of models show their increased understanding of the nature of models.

Relevance of modelling-based teaching in science teacher education

When asked about whether what they had done during the day had any relevance to their future profession as teachers, several PSTs said yes, but not all were able to elaborate. Those who gave reasons explained that the teaching plan showed how to work in a modelling-based manner with pupils and that they might use this exact teaching plan. They felt that the teaching plan displayed how visualising and reifying science concepts can make subjects more understandable for children. These PSTs also though the use of mock pupil models was smart because it enabled the teacher to steer the conversation and allowed pupils to practice evaluating and criticising models more freely, since the modeller was unknown.

> *One advantage of examples not constructed in class is that the teacher can have a very clear intention that this model explains one part well but is lacking in another area. So that if the discussion halts, you can guide it and help the pupils articulate what it does not illustrate well. […] On the other hand, it can be more challenging for the pupil to evaluate a model if they know the maker. – A2*

Putting the PSTs through an exemplary course in modelling-based teaching seemed to make them aware of how they could use these activities in their classroom. But they did note that the activities were time-demanding and might not be feasible in a school classroom, as science has little time on the timetable. Including selected parts of the teaching plan was, however, suggested as beneficial to pupils.

PSTs' ideas about the role and usefulness of models and modelling in school science (RQ2)

The other theme emerging from the analysis was the PSTs' ideas about the role and usefulness of models and modelling in school science. The related sub-themes were motivating diverse groups of learners, a better and deeper understanding of the subject under study as well as assessment and metacognition.

Motivating diverse groups of learners

Several PSTs indicated that engaging pupils was an important aspect of using models. In this context, one PST said that working with models can help simplify something for the pupils and, through this, help them to stay motivated regarding the subject:

> *It is important that it [science] is not too difficult either because then they will lose all motivation to continue. They will somewhat lose that … urge to explore. – A4*

One PST used the term 'exciting' to describe how teaching science using models might involve more pupils directly in the teaching. The PSTs mentioned examples of model usage from their own schooling, such as different sized balls for the Earth and the Sun. One PST pointed out that modelling was fun and added to the diversity in teaching methods:

> *It was difficult to represent it properly, but eh … at least it was fun. […] It is, it can be a very visual subject. Something I believe pupils think is fun. […] I think that is the forte of science. – B4*

The PSTs discussed how the use of models facilitated education adapted to different pupils' needs, noting how pupils preferred different ways of learning and how modelling afforded multiple types of expression. Two PSTs pointed out that modelling could make use of different pupils' strengths by allowing varied approaches, such as writing, drawing and so on. This, in turn, would make the teaching more adapted to each pupil.

A better and deeper understanding

The PSTs showed interest in how using the models could facilitate a deeper understanding of the subject under study. They mentioned the importance of seeing things for themselves or experiencing concrete artefacts as examples. According to them, tangible artefacts and concrete examples made it easier to learn and understand. They also mentioned the importance of using multiple visualisations for the same thing when teaching children.

Another PST raised the question of misconceptions and how pupils will always interpret new information in the context of what they already know. This PST believed that providing concrete artefacts and visual models would help to avoid such misunderstandings. It was also stated that using visual objects or models rather than listening to theoretical explanations would make it easier for pupils to learn.

Other advantages that were pointed out were how a model could be used to provide more details about a subject or to simplify it, possibly enabling a greater understanding of something quite complicated. Several PSTs said that using different models for the same system would enable a deeper understanding because they constituted different representations and, thus, offered repetition as well as progression in the subject. One PST said the following:

> *At the same time, we are displaying one phenomenon. It is all the same, so when you have several different methods and you get it explained and it becomes more and more advanced, it is a natural progression. Over time, you will develop a good understanding of what we actually did. – A2*

We interpret this as modelling the same phenomenon in different ways can make pupils aware of different aspects of the phenomenon and provide a more advanced understanding. The PSTs also noted that pupils who can translate between different representations of the same system show signs of deeper understanding.

Learning to model was regarded as important for pupils. The PSTs said they believed that pupils would gain a better or deeper understanding by modelling for themselves and that partaking in a process which raises questions was helpful to learning. One said that to model, you need to understand what you are modelling, whereas others believed modelling itself would help generate this understanding. Another PST put it like this:

> *You always learn a lot more by doing something yourself, so I believe that you remember things better and understand things better by sitting down and doing it yourself rather than receiving it from the teacher. Because then you run into challenges and problems that you need to figure out. That is, OK, how big should this be with respect to this and then you remember things better. – B2*

This PST emphasised that challenges and practical activities can help pupils to remember and achieve a deeper understanding. The PSTs also showed interest in how knowledge about models and modelling itself is built by using modelling-based teaching. One pointed out that by making and evaluating models, pupils can gain a better understanding of how models were used in science to develop knowledge:

> *[...] you evaluate each other's models and thereby gain a better understanding of how models can be used to understand something. – A5*

This quote is one example of how some PSTs appeared to have increased their awareness of the role and function of models in science and science education after the intervention.

Assessment and metacognition

The PSTs were interested in how modelling-based teaching may be used for communication in classrooms and for formative assessment. They noted that by modelling rather than answering questions, pupils' thoughts and ideas could become more accessible to the teacher, thus making it easier to give feedback. One PST noted the following:

> *And it will be easier to explain how they think with the aid of a model. And it is also easier for us to come in and say, 'Yes, I understand that you think this, but have you considered this?' – A5*

As the pupils make the models themselves, they will get to know their own ideas better, enabling self-assessment. Additionally, one PST pointed out that evaluating their own models may stimulate pupils' metacognition:

> *It could be nice to draw these different models and get the pupils to look at their own models and see the learning process they have had by looking at the first and the last. So, it is a nice way to, in a way, see their own learning. – A6*

In this way, the PST sees modelling as a way of making pupils aware of their own learning progress. Finally, the PSTs noted how engaging in modelling activities with others could be useful to pupils because it would facilitate discussion and argumentation. In such discussions, pupils are confronted with new information, and, thus, they can learn from it.

DISCUSSION

The two research questions in this study addressed how pre-service science teachers experience working with models and modelling as well as their ideas about the role and usefulness of models and modelling in school science. We found that there was a strong connection between these two questions and that the PSTs' experiences strongly influenced their ideas about how modelling would be useful in school.

The PSTs in our study lacked experience and knowledge about models and modelling when they created their first model. They found approaching the task difficult and felt frustrated working without a definitive, correct answer, which reveals they were not used to these teaching methods from their own schooling. This lack of experience resulted in their not knowing how to approach the task. Several PSTs stated that they had drawn a macroscopic picture of what they had seen. This finding is in line with multiple studies showing that PSTs hold naïve and simplistic views of models as replicas or copies of a real system prior to model- or modelling-based interventions (Danusso et al., 2010; Soulios & Psillos, 2016; Torres & Vasconcelos, 2017; Yenilmez Turkoglu & Oztekin, 2016). All science teachers should understand the meaning of a model beyond it merely being a copy or replica (Oh & Oh, 2011). For the PSTs in our study to obtain a more advanced understanding of models, we had to provide support mechanisms, such as asking questions about the models.

The PSTs found the modelling-based teaching plan useful for their professional education. Being exposed to different modelling-based activities made the PSTs consider how they might include such activities in a classroom with pupils, which is important for all science teachers (Oh & Oh, 2011). As developing modelling competence is essential to scientific literacy for 21st-century citizens (Chiu & Lin, 2019) and is part of modern science education (NDET, 2019; OECD, 2019), modelling practices must be included in teacher education to make teaching more process-oriented (Nielsen & Nielsen, 2019; Oh & Oh, 2011). Olufsen et al. (2017) found that PSTs who were educated with an emphasis on the connection between subject knowledge, education strategies and practice included teaching strategies learnt on campus in their own teaching. Our findings indicate that exemplary teaching in teacher education provided the PSTs with valuable knowledge and experience. And, as opposed to the findings of Aktan (2016), a lack of experience acting as an obstacle for modelling-based teaching in school was not apparent in our results.

The PSTs who were interviewed emphasised how motivating it was to have the opportunity to model a phenomenon they observed themselves and to get to make several iterations of it. They claimed, in line with previous studies (Aktan, 2016; Torres & Vasconcelos, 2017; Yenilmez Turkoglu & Oztekin, 2016), that the use of models in school would make science more exciting and enjoyable and would involve pupils directly in the teaching and increase their urge to further explore. This experience supports Oh and Oh's (2011) suggestions that cyclic modelling can improve teaching practices and that modelling-based scaffolding frameworks can enhance engagement in scientific practice (Chiu & Lin, 2019).

According to the PSTs in our study, the use of models would facilitate adapted education, allowing teachers to meet the educational needs of different pupils. This form of adaption is one of the goals of the Norwegian core curriculum, which calls for the use of a broad repertoire of learning activities and resources to create motivation and joy in the classroom (NDET, 2017). The use of models as an additional teaching strategy has also been pointed out by in-service teachers (Nielsen & Nielsen, 2019).

The PSTs in our study saw models and modelling as a way for teachers to access pupils' thoughts and ideas in line with practicing teachers (Nielsen & Nielsen, 2019), and they viewed models as concrete examples and tangible artefacts, which would make learning and understanding easier for children. The latter advantage is also noted in previous studies on both pre-service and in-service teachers (Nielsen & Nielsen, 2019; Yenilmez Turkoglu & Oztekin, 2016). In contrast, our findings also show that PSTs experienced the process of constructing models as challenging, but they believed this challenge would aid pupils in remembering and understanding the topic more deeply. To develop pupils' 21st-century skills, employing instructional programmes that engage learners in challenging tasks is recommended (Pellegrino & Hilton, 2012), and modelling could be an approach to achieving this.

According to the PSTs, performing modelling activities would not only require meta-modelling knowledge but also promote it. The use of multiple representations was thought to facilitate pupils' learning by representing a repetition of, as well as progression into, the subject modelled. Meta-modelling competence is important for science teachers (Oh & Oh, 2011), and the development of modelling competence is essential to scientific literacy (Chiu & Lin, 2019).

The PSTs found evaluating models to be difficult at first, but the questions opened their eyes about how to approach this task. These questions focused on the model's limitations, which might explain why the PSTs cited awareness of the models' scope and limitations as an important lesson, in line with the findings of Torres and Vasconcelos (2017). Knowledge about the limitations of models has previously been found lacking in the Norwegian curriculum (Vesterinen et al., 2009), but it appears, in our study, to follow naturally from evaluating multiple models for the same phenomenon. The PSTs in our study often critically evaluated whether a model supported various scientific claims and explanations, and they conceptualised non-observable objects and processes, which are important practices linked to models (Joolingen, 2004; Oh & Oh, 2011). Using models in this more elaborate way provides a link between learning discipline-specific knowledge and practicing skills, such as critical thinking and argumentation (OECD, 2019; Ryu et al., 2018), which is a goal of modern education (NDET, 2017; OECD, 2019; Pellegrino & Hilton, 2012).

At several points throughout the course, the PSTs engaged in self-assessment and meta-reflection about their level of content knowledge, and in the interviews, they pointed out that modelling would enable pupils to be aware of their own learning and learning progress. This implies that when provided with sufficient scaffolding, modelling can naturally lead to the goal of metacognition through reflecting on one's own learning, which is an important aspect of modern education (NDET, 2017; OECD, 2019; Pellegrino & Hilton, 2012).

Danusso et al. (2010) suggest a stronger focus on the components of scientific models in teacher education, and the findings in our study support this. LK20 states that modelling is central to scientific practices, which is in line with the OECD learning compass (OECD, 2019). A stronger focus on modelling would require a pedagogical transformation in science education involving model-thinking- and model-production-oriented approaches (Oh & Oh, 2011). Nielsen and Nielsen (2019) suggest that building on and extending established practices to make them more process-oriented is a way forward for teacher education. Our study shows that exposing PSTs to exemplary modelling-based teaching may promote their awareness of process-oriented teaching practices and their advantages.

CONCLUSIONS AND IMPLICATIONS

Models and modelling occupy a central position in modern science education, as they have been included in influential curricula around the world as well as in the Norwegian curriculum (NDET, 2019; NGSS Lead States, 2013). We have investigated how pre-service science teachers experienced working with models and modelling as pupils in an exemplary teaching sequence as well as their ideas about the role and usefulness of models and modelling in school science.

Some PSTs reported being engaged and motivated, especially by evaluating models, although they were challenged when making their first model. The challenges were overcome by scaffolding in the form of evaluation questions for the models. The most prominent learning outcome for the PSTs was their understanding that models have scopes and limitations, which has previously been missing in the Norwegian curriculum (Vesterinen et al., 2009).

The PSTs found modelling-based teaching to be useful in their professional education and envisaged using models and modelling as teachers. Some believed models and modelling made science education more exciting and would support the learning of a diverse group of pupils. Others believed models and modelling to enable deeper learning, facilitate pupils' self-assessment and provide opportunities for assessment by the teacher. Some also believed performing modelling activities would enhance the pupils' meta-modelling knowledge and force discussion and argumentation among the pupils.

Science teacher education could benefit from a stronger focus on models and modelling. Our findings suggest that Norwegian PSTs respond positively to modelling-based exemplary teaching. It appears the PSTs in our study are similar to other groups in which various interventions have been applied, resulting in an increased understanding of models and modelling (Danusso et al., 2010; Soulios & Psillos, 2016; Torres & Vasconcelos, 2017; Yenilmez Turkoglu & Oztekin, 2016). Using modelling-based teaching in science education additionally seems to promote the goals of modern education, such as metacognition and critical thinking. Therefore, we believe that exemplary modelling-based teaching could be an effective tool in Norwegian science teacher education in order to educate science teachers who promote such skills in the classroom.

LIMITATIONS AND SUGGESTIONS FOR FURTHER WORK

A limitation of this study is the narrow selection of participants and that it has only been performed in one teacher education institution. Therefore, it might be interesting to perform a more comprehensive study that includes a larger population of PSTs as well as practicing science teachers.

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APPENDIX A – INTERVJUGUIDE FOR GRUPPEINTERVJU

«Arbeid med modeller og modellering i kjemi»

OsloMet – storbyuniversitetet

Innledning

Velkommen til denne uformelle samtalen om hvordan dere opplevde å jobbe med modeller og modellering i kjemi.

Som dere kjenner til (fordi dere har samtykket i å delta i denne fokusgruppesamtalen), ønsker vi å drive forskning på naturfaglæreres forståelse om modeller i kjemi, etter å ha gjennomgått det undervisningsopplegget dere var med på i går.

Vi skal nå ha en uformell samtale omkring deres erfaringer med modeller og modellering. Vi ønsker å intervjue dere om erfaringene dere gjorde dere i løpet av undervisningsopplegget dere var med på i går. Det vi undersøker er hvordan lærerstudenter opplever å jobbe med modeller og modellering i kjemi og hvordan de forestiller seg å bruke det i egen praksis.

Det er frivillig å delta i denne diskusjonen, og du kan når som helst, uten begrunnelse, trekke deg.

Vi ønsker å gjøre videoopptak av diskusjonen for å lettere kunne gjenkjenne hvem som snakker når intervjuet senere skal transkriberes. Opptaket skal bare brukes til forsknings- og dokumentasjonsformål og vil behandles konfidensielt; du vil ikke identifiseres med navn eller kunne gjenkjennes på annen måte i rapporter fra forskningen. For opptaket sin del er det fint om dere snakker én om gangen (selv om vi skjønner at dere kan bli ivrige ☺)

Ønsker noen å trekke seg? Hvis ikke, starter vi diskusjonen og videoopptaket. Vi ønsker at dere i størst mulig grad skal diskutere med hverandre ut fra relativt åpne spørsmål og temaer som vi tar opp.

Start opptaket

Om å arbeide med modeller og modellering

Hvordan opplevde dere å jobbe med modeller og modellering i går?

- Opplevde dere noe som vanskelig eller enkelt? I så fall hva?
- Hvordan synes dere det var å lage den første modellen dere tegnet?
- Hva synes dere om å revidere modellen? Var det nyttig, unyttig, enkelt, vanskelig?
- Hvordan synes dere det var å vurdere de ferdige elev-modellene?

Opplevde dere at dere lærte noe om modeller og modellering i går? I så fall når og hva?

Om å bruke modeller og modellering i egen praksis

Hvordan tenker dere at modeller kan brukes i naturfagundervisning?

- Hva kan lærere bruke de til?
- Hva kan elever bruke de til?

Hvordan tenker dere at modellering kan brukes i naturfagundervisning?

- Hva kan være positivt ved at elever lager egne modeller?
- Hvilke utfordringer tror dere kan være knyttet til at elever lager egne modeller?

Hva tror dere elever vil synes er mest utfordrende: å lage en egen modell eller å vurdere noen andres? Hvorfor?

Hva mener dere kjennetegner en god modell for bruk i naturfagundervisning? Hvorfor?

Om modeller og modellering

- Hva oppfatter dere at en modell er?
- Hva oppfatter dere at modellering er?
- Er det forskjeller på modeller i naturvitenskap og naturfagundervisning? Hvis JA, hvilke?

Avslutningsspørsmål

- Er det noe mer dere gjerne vil snakke om angående modeller og modellering?

APPENDIX B – QUOTES

Quotes used in the article in original language and translation, in the order of appearance.

Norwegian	*English*
Synes den første revideringa var veldig lik det jeg gjorde. De var første ble velig like, for da var vi ikke presentert for noen nye kriterier egentlig for hva som skulle være med. Hvertfall ikke som jeg oppfattet. Jeg synes den første var litt sånn... Ja, ok, jeg var egentlig litt fornøyd med åssen den første så ut. Og så jaja, vi får prøve på en litt annen måte også... prøvde man det. Med en gang du fikk, som vi snakket om i stad, de kriteriene så synes jeg det var mye.. Både mer utfordrende men også, jeg fikk en mer, mye bedre modell da, med en gang jeg visste hva jeg skulle lage den ut ifra. – A2	*I felt that the first revision was very similar to the first one I made because we weren't really introduced to any new criteria. At least not to my knowledge. I was pretty happy with how my first model turned out, so I was like, 'Okay, well, let's try a different approach', which I did. But as soon as we got those criteria [evaluation questions], I felt that it got more challenging. But, also, I got a much, much better model out of it because now I knew what to convey with the model. – A2*
Du får oversikt over hva du forstår og hva som ikke forstås på en måte. Det skjønte hvertfall jeg når vi holdt på med den siste modellen egentlig er det bare har jeg virkelig skjønt dette (utydelig) ide det hele tatt. Eller hva har jeg av kunnskap og hva har jeg ikke? – A3	*You get an overview of what you understand and what you don't understand, in a way. At least that's what I realised when we were working on our final model. Have I really understood this at all? Or what knowledge do I have and what knowledge am I missing? – A3*
Også når en selv tegner sine tanker, så forståren veldig godt sitt bilde selv. Men når en da bytter med en annen, så skjønner en jo kanskje bare, åja, det var ikke så lett allikevel, på en måte. Da ser en mye mer hvor en må være tydelig. – A1	*When you draw your own thoughts, you know exactly what you mean by what you are drawing. But when you switch with someone else, you realise that, yeah, maybe it wasn't that easy. It makes you more aware of where the model needs to be more explicit. – A1*
Jeg tenker en fordel med det å ha med eksempler som ikke er laget i klassen er jo at da har du jo som regel som lærer en veldig klar intensjon på at ok denne modellen forklarer dette veldig godt, men så mangler vi litt på dette området her. Og da, hvis en diskusjon eventuelt går litt i stå så kan du jo eh legge litt	*One advantage of examples not constructed in class is that the teacher can have a very clear intention that this model explains one part well but is lacking in another area. So that if the discussion halts, you can guide it and help the pupils articulate what it does not illustrate well.[...] On the other hand, it can be more*

føringer, være litt mer (utydelig) og sette elevene litt til å sette ord på det modellen ikke illustrerer så godt da. […] I motsetning til hvis du har en elevlaget eh modell, som kan potensielt også sette deg litt inn i før du begynner å snakke om det samtidig sånn som "S5" sier at det kan være mer utfordrende for eleven også å vurdere en modell som du kjenner noen som har laget. – A2	*challenging for the pupil to evaluate a model if they know the maker. – A2*
Det er viktig at det ikke blir for vanskelig heller, for da mister dem jo all motivasjon til å holde på med det. Dem mister litt den derre... utforskergleden. – A4	*It is important that it [science] is not too difficult either because then they will lose all motivation to continue. They will somewhat lose that … urge to explore. – A4*
[…] så det er vanskelig å klare å framstille det sånn skikkelig men eh.... det var gøy da hvertfall. […] Det er, det kan være et veldig visuelt fag. Eh, noe, eh, jeg tror elever syns er veldig gøy da.[…] Det tror jeg er den store forsen til naturfag da. – B4	*It was difficult to represent it properly, but eh … at least it was fun. […] It is, it can be a very visual subject. Something I believe pupils think is fun. […] I think that is the forte of science. – B4*
Samtidig så representerer jo, eller vi skal jo vise ett fenomen. Det er jo, alt er jo av det samme, så du, når du får liksom så mange metoder å gjøre det på og du får det forklart og det blir mer og mer avansert, og det blir.. det er liksom en naturlig progresjon i hele opplegget da, så du vil jo få... over tid da så vil du jo få en ganske god forståelse av hva er det vi faktisk har gjort. – A2	*At the same time, we are displaying one phenomenon. It is all the same, so when you have several different methods and you get it explained and it becomes more and more advanced, it is a natural progression. Over time, you will develop a good understanding of what we actually did. – A2*
Man lærer jo alltid mye mer når man gjør selv på en måte, eh, så jeg tror jo man husker ting bedre og forstår ting bedre ved å sette oss å gjøre det selv, kontra å få det utdelt av læreren.	*You always learn a lot more by doing something yourself, so I believe that you remember things better and understand things better by sitting down and doing it yourself*

For da støter du jo på liksom utfordringer og problemer som du må finne ut av. Som er, sånn, "okei hvor stor skal den være i forhold til den" og så...ja, da husker man ting bedre. – B2	*rather than receiving it from the teacher. Because then you run into challenges and problems that you need to figure out. That is, OK, how big should this be with respect to this and then you remember things better. – B2*
[…] man ehh vurderer hverandres modeller og dermed liksom får bedre forståelse for hvordan modeller kan brukes da for å forstå ting. – A5	*[…] you evaluate each other's models and thereby gain a better understanding of how models can be used to understand something. – A5*
[…] Og det vil være lettere å forklare med en modell eller ved hjelp av en modell hvordan de tenker da. Eh og det er jo også da lettere for oss å komme inn og si ja ja jeg skjønner at du tenker alt det der men har du tenkt det og det. […] – A5	*And it will be easier to explain how they think with the aid of a model. And it is also easier for us to come in and say, 'Yes, I understand that you think this, but have you considered this?' – A5*
Det kan være fint og da, å på en måte tegne disse forskjellige modellene og så få elevene til å se på sine egne modeller og se læringsprosessen de selv har hatt ved å se på den første og den siste. Så er det jo en god måte å på en måte se sin egen læring i da. – A6	*It could be nice to draw these different models and get the pupils to look at their own models and see the learning process they have had by looking at the first and the last. So, it is a nice way to, in a way, see their own learning. – A6*