Abstract

It is important to be able to make better informed decisions about issues such as sustainability and climate change that have both personal and global impact as early as possible in life. Primary teachers have a significant role in supporting students’ learning and understanding of these concepts. One important teaching skill that needs to be improved for understand sustainable development is the creation of meaningful generalizations, including models. Therefore, the learning experiences of pre-service primary teachers (N = 28) in regard to modelling was our focus. The results of our case study indicated concrete and visual modes as most common in student teachers’ experiences and understandings of modelling. The symbolic mode is less in evidence and an understanding of gestural and verbal models is rather unambiguous. Thus, we see a need and the potential to improve teaching and learning experiences in teacher education about the modelling of complex concepts.

Keywords: concept learning, formula map, modelling, primary education, student teacher, sustainable development, teacher education

Introduction

Contemporary trends in the development of primary education address the large-scale challenges of modern societies. In formal education, non-formal and informal learning, the teaching profession needs to do more to promote the development of the general and future competences required to become a responsible citizen, alongside subject-related and professional knowledge and skills (Education Strategy 2021–2035, 2020). We need to notice and value everyone in education and to guarantee opportunities for all learners to acquire the knowledge, skills and attitudes that enable individuals to cope and succeed in ever-changing circumstances and to make the most of their potential in personal and collective prosperity (Education Strategy 2021–2035, 2020). Accordingly, education is being re-defined to include global existential and value-laden aspects, and could be considered as education for sustainable development (cf. Bell, 2013; Bentham, 2013; Pipere et al., 2010). Sustainable development is a process that involves political,
economic and societal dimensions (Bentham, 2013) and should not be reduced to one single specific aim. Instead, the great variety of human activities which have an environmental impact should be in focus at schools. These ambitious challenges should be addressed both in teacher education and in teaching practices (Mandolini, 2009; Ruus & Timoššuk, 2014). Science could serve as a core subject in that process as a proactive engagement of learners early in their school career with science that has the potential to fill some of the gaps that are seen further down the line in terms of recruitment to science employment and the development of a truly scientifically literate society (Hoath, 2021).

It is important for teachers to be able to learn more and to be able to make more informed decisions about issues that have both personal and global impact, such as sustainability and climate change, as early as possible in their teacher education (Hoath, 2021). Primary teachers have a significant role in supporting student learning and understanding of science concepts. Accordingly, relevant domains in primary teacher education about science and science teaching are our focus. We recognize that student teachers’ learning experiences have a deep impact on their understanding of the role of a teacher in supporting students’ acquisition of scientific skills (Timoššuk, 2016). Primary teachers lay the foundations for science education and thus their science knowledge and science teaching skills need to be developed to address different levels of epistemological understanding of pupils’ learning (Kang, 2007) including dealing with misconceptions (Gomez-Zweip, 2008). One important science-teaching skill that needs to be improved is the creation of meaningful generalizations, including models. This skill is closely related to concept learning because concepts are the building blocks of thought (Unsworth & Medin, 2010). Teaching concepts assume knowledge about the essence of the concept. Using models in primary science can help organize students’ thoughts. Modelling can also be considered a pedagogical tool for creating conceptual links between humanity and nature, thus diminishing anthropocentrism. Thus, more adequate self-image of students can be supported as the need for that is recognized especially in the context of the sustainable development (cf. Salite et al., 2021).

Supporting modelling, however, requires good pedagogical content knowledge, including a deep understanding of a scientific phenomenon (cf. Fortus & Krajcik, 2012; Schneider & Plasman, 2011). Teachers should therefore help students learn major models, learn the nature of the models and learn how to produce and revise the models (Henze et al., 2007). The profound knowledge helps teachers face the paradox which comes with the progressive nature of the subject and whether education and society will always be chasing the tail of the development of science and what it can do and is doing (Hoath, 2021). Nevertheless, pre-service primary teachers tend to think quite traditionally about the future challenges of their students based on their own learning experiences (cf. Nurmilaakso, 2009). We, therefore, recognize the need for improvement of primary teachers’ preparation for science teaching and that we need more detailed information about the gaps in student teachers’ understanding of modelling in science. Based on that knowledge we can improve science teaching for primary teachers at the university level.

Our aim is to explore student teachers’ science modelling experience and attitudes about science modelling in the primary grades. We designed a case study, the aims of which were to 1) explore student teachers’ experience in compiling and using formula map as one example of modelling in science and, 2) to find out how future primary school teachers understand the value of formula map for a concept learning in teaching primary students. By formula map we mean a modification of a concept map, where
the focus is on a specific formula describing the law of nature (in our case Coulomb’s law, an experimental law of physics).

**Science Modelling in Primary School**

The current application of models in teaching gradually moves from concrete material models to more abstract models. However, the use of specific and often complex symbol-based models can lead to a decline in students’ interest in natural science (Gilbert, 2007). If the learner believes that learning science is a dull and difficult experience, teachers should give samples of meaningful and enjoyable science learning experiences (Champagne & Klopfer, 2006). An example of exciting learning activities is the use of role-playing games to explain simple connections or even more complex models (Foreman, 2005). Thus, it is necessary to involve students in learning about nature in an age-appropriate way. In order to be involved, clear instructions should be given, students’ interest should be stimulated, and previous experience should be taken into account (Näkk & Timoššuk, 2019). Students’ perceptions are subjective and selective, and their prior knowledge, expectations, and prejudices determine the information that attracts attention (cf. Harlen, 2006). Students learn what they notice. In other words, students understand new information, ideas and experiences based on their existing knowledge (Harlen, 2006). Accordingly, students need to be given opportunities to make sense of what is learned by negotiating the meaning – comparing what is known to new experiences (Lorsbach & Tobin, 1992). Such a metacognitive process is particularly important for the learner, as it leads the student from the role of a passive learner to the position of an active learner – this is important to support students to achieve their learning goals (Darling-Hammond et al., 2020).

In order to associate experiences with new knowledge and to create new cognitive structures, it is very important to practice modelling from an early school age and to develop students’ holistic understanding of diverse models (cf. Boulter, 2000; Boulter & Gilbert, 2005). For example, using concept maps makes children learning about environmental issues relevant, meaningful and, in the long run, conducive to improved environmental responsible behavior (Vanhear & Pace, 2009). Practicing the creation and use of simpler models will help students better deal later with complex symbol-based models (Boulter & Gilbert, 2005). Accordingly, student teachers tend to value the concept map as a learning tool about the environment related issues (Pontes-Pedrajas & Varon-Martínez, 2014).

In the present study, we distinguish between different modes of models: the concrete (or material) mode (tactile models, e.g., solar system model); the verbal mode (expressed either in writing or orally, including the use of metaphors, e.g., interactions between particles are like springs between balls); the symbolic mode (formulas, equations, mathematical expressions); the visual mode (graphs, charts, animations, simulations); the gestural mode (expressions through the movement of body parts e.g. students are particles whose chaotic movement expresses the heat transfer of bodies) (Gilbert, 2005, p. 13).

Considering the complexity and variations of modelling we bear in mind that the more interesting and appropriate methods teachers use in teaching natural science, the more students are involved in science lessons (Timoššuk & Näkk, 2020). It is equally important to address this issue in primary school teacher’ education in order to give them...
a broader picture and experience of using various models. We focus on a more complex symbolic mode in our study.

We consider a special form of a concept map as a formula map, the main purpose of which is to better visualize, decipher or understand the relationships in a symbol-based model. Similar processes of visualization are widely used throughout science and science education (Gilbert, 2007) and therefore teaching materials that include illustrative pictures, diagrams, etc. help better interpret data and create in learners a more positive attitude towards learning (Vavra et al., 2011). In order to create a formula map, the metacognitive ability of the learner is important, which means that the learner understands the importance of monitoring new knowledge as well as the importance of integrating and expanding knowledge by visualization (cf. Gilbert, 2007).

The Aim and the Steps of the Study

The aim of our study is to explore student teachers’ science modelling experiences and attitudes about science modelling in primary grades. We designed a case study, the aims of which were to 1) explore student teachers experience in compiling and using formula map as one example of modelling in science and, 2) to discover how future primary school teachers understand the value of formula map for learning a concept when teaching primary students. By formula map we mean a modification of a concept map, where the focus is on a specific formula describing the law of nature (in our case Coulomb’s law, an experimental law of physics).

The study was conducted in three stages.

The first stage was the introduction of different modes of modelling in science (concrete; verbal; symbolic; visual; gestural cf. Gilbert, 2007) and creating an example formula map. The symbolic mode of formula map was chosen – a more complex form of modelling.

Before creating the formula map, students received a theoretical overview of Coulomb’s law and its relationship with other concepts. Then the formula mapping process was explained. Students were asked to write down any questions that arose when first looking at the formula. Based on the answers, students showed how they had visualized the formula and highlighted relevant information. Thus, the formula map could include the physical quantities in Coulomb’s law, and both standardized and unstandardized units. Applications of a particular law in nature or in everyday human life can be demonstrated on a formula map. For example, in the case of electrostatic force, we can draw a parallel with gravitational force. These diverse connections and examples can help create a holistic understanding of nature and students’ knowledge may be better consolidated.

Analyzing student teachers’ experiences, we were not interested in how many different relationships the formula map contained, but in understanding of the nature of the formula map as a model of the natural phenomenon. We used an open-ended question for this purpose: What connections can you see between the two tasks – composing the formula map and answering the questions?

The second stage was data collection about students’ experiences and reflections on modelling in primary science education. We used a questionnaire (see Appendix 1).
The questions focus on different types of activities for science teaching and science modelling such as learning about major models (questions 1–3), learning about the nature of models (questions 4–8) and learning how to produce and revise the models (questions 9–12) (Henze et al., 2007). Our intention was to capture the richness of student teachers’ understanding of modelling and we asked students to comment on their answers to the questionnaire in on-line sessions.

The third stage was designed to link student teachers’ learning experience about formula map to their future profession. We asked student teachers to think about their experiences of using a formula map and to think about different modes of modelling in primary school. We wanted to know if the process of compiling a formula map broadened their understanding of the use of models in primary school.

All data were collected and oral responses were transcribed. We used qualitative content analysis for the collected data at every step.

Participants and the Context of the Study

28 student teachers from the primary school teacher program of Tallinn University took part in our study. The total worth of this program is 300 credit points (ECTS credit system). The nominal duration of study is five years. During their studies, students are required to pass compulsory courses in a variety of subjects (37 ECTS). The compulsory courses include natural science subjects worth nine credit points and a course of science teaching of six ECTS.

In Estonia, the 6th grade (students aged 11–12) is the last grade of primary education. Up to the 4th and in some cases up to the 6th grade there is usually only one primary school teacher who organizes the learning process, although some subject teachers may also be involved.

We conducted our case study as a part of The Inanimate Natural Environment course in May 2021; the course aimed at first-year students. In this compulsory course, student teachers consolidate their basic knowledge of science, in order to develop a wider scientific horizon and work as a primary school teacher. One of the topics of the course is energy. We recognize energy education among the priorities in sustainability-oriented teacher education as energy is the central issue to sustainable development (Hamdan Alghamdi & El-Hassan, 2019; Pipere et al., 2010; Tellegen, 2006). Therefore, we chose to look at an example of the study of electrical phenomena, namely Coulomb’s law, a major law. In order, to better understand and describe this complicated natural science law, student teachers compiled a formula map.

Results and Discussion

Creating a Formula Map

The majority of student teachers highlighted that compiling a formula map was exciting. They explained: “If I can make a phenomenon artistically understandable through a formula map, I will remember it better.”; “I realized that there is much to be gained with a formula map. You can describe history and applications – a complete picture of the phenomenon emerges”. The formula map helps us to understand how relationships are made”. Some concerns were expressed: “It was difficult to compile a
formula map in the beginning, because I wanted it to be bright and attractive. I had doubts about rights and wrongs”. Thus, student teachers recognized the motivating aspect of a formula map and also the need for profound knowledge in order to make their thinking visible. The rich context of the formula was visualized in all maps (see one example in Figure 1).

**Figure 1**

*Formula Map of Coulomb’s Law*

Perceptions and Attitudes Towards Modelling in Primary School

**Variety of Models**

We wanted to know which models were suitable for primary school children. The answers indicated that the student teachers would use material and visual models the most. Verbal and gestural models would be applied significantly less. The symbol-based model would be used only by some student teachers.

The most popular material model was the globe. A globe can be crafted together with pupils: “Paper can be glued around an inflated balloon, and later, once it has dried, you can draw the oceans and land on it.” The solar system model was also very popular. “Fruits can be used to illustrate the sizes of the planets. For example, the watermelon corresponds to Jupiter and cherry tomatoes to Earth. Another exciting example of a model that presents a direct link with the home environment was “a model where students could collect, for example, 10 objects around their home for use in modelling the habitat.”
Many general examples of visual models using information and communication technology were described: various simulations and computer programs, images and video materials such as nature cameras. As discussions and other verbal methods are prevalent in primary classrooms, student teachers emphasized that each verbal model must be explained clearly and with the simplest possible vocabulary. Some exciting metaphors were cited as examples of verbally modelling nature. One described the solar system as follows: “The teacher is like the sun – children run around her like planets.” Another metaphor was about weather changes that were compared to a moody person.

One example explained Ohm’s law triangle with symbols.

Using Models to Make Learning More Playful

We asked students to consider possible elements of play when describing teaching major models. Student teachers thought that material models offered the most opportunities for playful learning. Visual and gestural models were described significantly less. Symbol-based models and verbal models were considered to have very little potential for playfulness. Nevertheless, one example given by a student teacher about composing various nature-themed songs and singing the songs in class did indeed have elements of play. The low use of symbol-based models in this context was predictable. The idea, however, that different formulas could be expressed by using toy blocks is worth highlighting. Another idea came from a lesson in a play center using a trampoline, where playful thoughts might arise that could be used when compiling computational tasks.

Using Models to Compile Learning Tasks

Relatively few examples were given about using models to compile learning tasks. Nevertheless, visual and material models are again the most popular among student teachers. “In science education, it is very effective if children can actually touch things when introducing the topic”. Different content specific examples from student teachers were also explained: “Studying different trees could involve picking the leaves and identifying and categorizing them.”; “Models could be used to introduce a topic, make it more understandable, a visual design can create a complete picture.”

Symbol-based, verbal and gestural models are less applicable in task creation in the opinion of student teachers.

The Aim of Models in Learning About Nature

The student teachers see models most of all as magnifying or reducing natural objects and phenomena. Several student teachers mentioned that models simplify reality. Few respondents mentioned that models help better study or analyze the object. Other qualities such as access, richness and specificity were mentioned, surprisingly, only once. A need to support creativity was pointed out only once and was again somewhat surprising, because creative had an important role in primary school learning.

The Similarity or Difference of Models With Nature

We were interested in how primary school student teachers would explain to students the similarities and differences between the model and the natural phenomenon.

Only one feature was highlighted as a similarity between the model and a natural phenomenon, and that is what it looks like. This was noted by half of the respondents.
More features were noted as differences. The difference in dimensions between the model and a natural phenomenon, cropped up the most as concrete objects prevail in primary education. Differences in clarity or perception (models give a more comprehensive picture), detail and functionality (models are simplifications) were also mentioned. Some respondents mentioned the material of models could be different.

The Changing Understanding of Models

Most student teachers cited reasons why models used to facilitate teaching have changed. The explanations were, in the main, similar. The three main reasons given were: nature itself is changing; the scope of knowledge has grown significantly; research techniques have advanced. There were few differences in opinions with regard to the methodology for explaining changes. Verbal explanation, supported by visual materials (pictures, videos, etc.), was mentioned the most. Few student teachers indicated that models were used for analytical activity, using, for example, data tables or graphs to study natural phenomena (for example, the modelling of weather, where the parameters of weather from decades ago are analyzed and compared with current data).

The Usefulness of Models in Teaching

As expected, the importance of using models to improve the understanding of big scale natural phenomenon was mentioned the most: “Modelling gives us the opportunity to understand the movement of the planets, we don’t just have to imagine it, we can experience how it happens.” The opinion that the use of models creates better connections between new and existing knowledge was also explained. Few student teachers mentioned that the use of models made teaching more effective: “I would explain the usefulness of the model as supporting pupils by enabling them to acquire information more easily or meeting their goals”. Some mentioned that the use of models helps better analyze the laws of nature. Other positive qualities of models such as supporting decision-making, developing students’ crafting skill and helping to connect theory with practice were mentioned only once.

The Criteria for Model Selection

The student teachers mentioned most that they would let their students play with the models themselves, try them out, and then choose one. In other words, the selection of the model should be in line with students’ abilities and interest. The connection between the information and features with the laws of nature or the phenomenon itself was considered just as important, i.e., the model must be as true as possible. The significance and the attractiveness of the model, the excitement it generated, the age-appropriateness and simplicity, reliability and functionality were less mentioned.

Supporting Pupils in Working with Models

More than half of the student teachers in the study consider it important that pupils should be guided to study the model. It is also considered very important, if possible, to formulate a hypothesis before working with the model and that the formulation of a hypothesis must be followed by the testing of the hypothesis. Creating a helping worksheet and class discussions about models were mentioned. One respondent considered it important to perform several different modelling sessions or experiments in order to obtain
more credible final results. Furthermore, the experimental control was mentioned as relevant.

**Helping Pupils to Understand the Nature of Models**

The student teachers thought that the nature of models could best be conveyed through a verbal explanation of differences and similarities between the model and the phenomenon. Video materials and simulation programs were recognized as helpful for explaining differences and similarities. Methods for analyzing models by numerical (mathematical) comparison or by using technology (for example, a microscope) were mentioned less. Some respondents considered it important that there was a direct comparison of the model with nature. For example, a model could be analyzed by visiting a nature museum or zoo, where the model could be compared to an exhibit.

**Students as Creators of Models**

The autonomy of the learner was valued. Most of the student teachers thought that the best way to help primary pupils create models was through crafts. The role of drawings was also highlighted. Modelling by using diagrams and tables or modelling on a computer by making programs and simulations as well as the collection of inspiring ideas from the Internet was mentioned by some student teachers. Only one respondent would like to help primary pupils create mathematical models.

**Directing Pupils to Discuss Their Own Models**

Though, student teachers provided a variety of answers, one approach prevailed – the need for unstructured open discussion was highlighted. The importance of having pupils give presentations in different formats such as oral presentation, posters, drawings or videos was mentioned. Some student teachers noted that it was important for pupils to be able to compare models with peers and thus stimulate discussion. Accordingly, cooperation was highlighted. It is worth noting that after the discussion, pupils could be asked to work further on the content of their model. A need for a clear structure of the task, relevant instructions and open discussion was mentioned several times.

**Formula Map as an Additional Model in the Teacher’s Toolbox**

We asked student teachers to think about their experiences using a formula map and about the different modes of modelling in primary school. We wanted to know if the process of compiling a formula map broadened their understanding of the use of models in primary school.

About half of the student teachers mentioned the process of modelling as helpful for understanding the essence of modelling in primary school “I am able to make better models now – I made the formula map on one specific topic, but now I think about different models much more broadly”; “In the past, modelling was more basic for me, I had a model menu. I now understand that formula analysis or using gestures or purposeful play can also be modelling.”

One student teacher pointed out: “I realized that if the models were to be applied, hard work had to be done and the topic should be clear for me”. Nevertheless, some student teachers said that it was hard for them to link formula maps with modelling in
primary science lessons and this was alarming. We conclude from these responses that knowledge transfer from initial teacher training to primary classroom should be supported.

**Conclusion**

It is important to be able to make better informed decisions about issues such as sustainability and climate change that have both personal and global impact as early as possible in life. Primary education was therefore the focus of our study. Moreover, we wanted to obtain more information for developing initial teacher education. One important skill that needs to be improved is the creation of generalizations, including models. This skill is closely related to concept learning and concepts are the building blocks of thoughts (Unsworth & Medin, 2010). Furthermore, the meaningful relationship between humanity and nature could be addressed by the modelling process. Avoiding anthropocentrism should be then highlighted by the teacher.

We can conclude that student teachers consider modelling to be very important. Student teachers understand through practical experience that models help make learning more effective because things that are connected with one another are better remembered. Future teachers aimed to make the most use of material and visual models in their teaching. Material and visual models also create many opportunities for playful activities. Somewhat surprisingly, only a few examples of the playfulness of verbal models were brought (cf. Foreman, 2005).

The fact that the students realized that there was a clear connection between compiling a formula map and addressing issues of science teaching in primary school could be considered significant because this indicated that students could transfer the value of sophisticated modelling into age appropriate activities in primary school. In other words, student teachers recognize the need for and value of multimodal teaching (cf. Furu et al., 2021). Nevertheless, we see a need and the potential to improve teaching and learning experiences in teacher education about the modelling of complex concepts. A good balance between different modes of modelling such as concrete (or material) mode, the verbal mode, the symbolic mode, the visual mode and the gestural mode (Gilbert, 2005, p. 13) should be encouraged. We also conclude that a further exploration of the pre-service teachers’ experiences and skills of modelling at classroom level during the practical classes could provide additional information for improving the teacher education.

**References**


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Appendix 1

Questionnaire:

1. Which models can be used to learn about nature with primary school children? Give examples.
2. How could models be used in a playful manner to help students learn more about nature?
3. How could models be used to design learning tasks?
4. How would you explain to your students the features (properties) and purpose of natural models in science (why are models needed at all?)
5. How would you explain to students the similarities and differences between a model and the corresponding natural phenomenon?
6. How would you explain to students that perceptions of a particular modeled natural phenomenon may have changed in history?
7. If your students observe a natural phenomenon and use a model to describe it, how would you explain to them the usefulness of a model?
8. How would you help students decide why one model is better than another?
9. How would you use a model to help students to make hypothesis and test them? Give an example!
10. How would you help students to understand that a model expresses the features of a natural phenomenon in a generalized and reduced (or even enlarged) way?
11. How would you help students to create simple models by themselves?
12. How would you teach students to discuss self-created models?