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EURASIA Journal of Mathematics, Science and Technology Education, 2021, 17(4), em1954
ISSN:1305-8223 (online)
Research Paper https://doi.org/10.29333/ejmste/10790

Models and Modelling: Science Teachers' Perceived Practice and Rationales in Lower Secondary School in the Context of a Revised Competence-Oriented Curriculum

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Received 22 December 2020 ▪ Accepted 12 March 2021

Abstract

As part of curriculum reforms, models and modelling (MoMo) are playing an increasingly prominent role in science education. Through a questionnaire study, this paper investigates lower secondary school teachers' (n = 246) perceived practices of, rationales behind, and possibilities for working with MoMo in the context of the revised science curriculum. Our findings suggest that: (1) teachers prioritize the subject-specific knowledge embedded in models over and above the modelling process and meta-knowledge; (2) teachers prioritize engaging students in MoMo activities for descriptive rather than predictive purposes; (3) the process of designing, evaluating and revising models based on students' own inquiry only plays a minor role in teachers' practice and; (4) a content-heavy curriculum and multiple-choice exam are counterproductive to teachers' efforts to implement a more competence-oriented approach to MoMo. Our study also sheds light on, and discusses implications for, how to enhance teachers' possibilities of teaching for modelling-competence.

Keywords: modelling, modelling competence, models, science curriculum reform, science teachers' practices and rationales, scientific practices

INTRODUCTION

International efforts to engage students in scientific practices have increasingly shifted from the aim of developing students' content knowledge towards a competence-oriented approach in which the focus is on teaching students how to use scientific knowledge (Berland et al., 2016; Crujeiras & Jiménez-Aleixandre, 2013; Ministry of Education, 2014; NRC, 2012; OECD, 2017, 2019). Modelling is a type of practice with which students can engage in the science classroom. As such, modelling is becoming increasingly key to curriculum development and science educators (e.g., Campbell & Oh, 2015; Krell, Reinisch & Krüger, 2015; Lin, 2014; NRC, 2012). While some scholars argue that modelling is at the very core of science as a knowledge-generating discipline (Lehrer & Schauble, 2015) others go even further to argue that this centrality, together with a host of pedagogical and theoretical learning benefits offered by modelling activities, places modelling right at the heart of any efforts to devise a curriculum aimed at building scientific literacy (Gilbert & Justi, 2016). Moreover, several scholars have pointed to the opportunities modelling offers in facilitating students' learning of science concepts, scientific reasoning processes and awareness of how science works (Campbell & Oh, 2015; Nicolaou & Constantinou, 2014). Recent science education research, however, has demonstrated that teachers' understanding of MoMo, as well as how teachers implement MoMo in their teaching and their rationale in this regard, is a primary factor in whether the potential benefits of working with MoMo are realized or not (Khan, 2011; Krell & Krüger, 2016; Miller & Kastens, 2018; Nielsen & Nielsen, 2019; Oh & Oh, 2011).

Through an electronic questionnaire survey, this paper investigates lower-secondary school science teachers' perceived practices of, rationales behind, and possibilities for working with MoMo in their teaching in the context of a revised competence-oriented Danish

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Contribution to the literature

- This paper seeks to elucidate how science teachers perceive their own implementation of a curriculum intended to teach for modelling competence, as well as their rationales and possibilities in this regard.
- It also analyses how teachers' perceived practice of and rationales for integrating MoMo into their teaching align with a competence-oriented approach to MoMo.
- This study not only indicates a gap in alignment but also suggests ideas for improving that alignment based on the opportunities teachers have and the challenges they face in changing their practice towards a more competence-oriented approach.

curriculum. As such, the paper is intended to be relevant to all international contexts in which MoMo is part of or has been recently introduced into the curriculum. The paper should also be considered relevant in the light of international efforts to redirect science education towards a more competence-oriented and authentic approach.

BACKGROUND AND RESEARCH QUESTIONS

While the noun 'model' could be perceived as the product of a scientific process, the verb 'modelling' can be understand as the conducting of a scientific process that involves: (a) developing models by embodying key aspects of theory and data into a model; (b) evaluating models; (c) revising models to accommodate new theoretical ideas or empirical findings; and (d) using models to predict and explain the world (Schwarz & White, 2005). The process of modelling involves repeated cycles of developing, representing, and testing knowledge, and it is therefore argued that modelling plays a central role in the processes of scientific inquiry (Lehrer & Schauble, 2015). Indeed, some have argued that science - as a research endeavour - is first and foremost a 'modelling enterprise'; that modelling thus ought to be the core scientific practice in school science; and that this would facilitate the use of other scientific practices in teaching - e.g. formulating researchable questions, recording data, recognizing data patterns, constructing explanations for data, evaluating information or constructing causal explanations (Lehrer & Schauble, 2015; Windschitl, Thompson, & Braaten, 2008).

In this light, the role that models play in science goes beyond the conventional use of models (namely describing and explaining) in science teaching (Justi & Gilbert, 2002; Miller & Kastens, 2018). The modelling process, which involves repeated cycles of developing, evaluating and revising, likewise reflects an approach to inquiry different to the step-by-step approach to inquiry that still dominates school science teaching today (Windschitl et al., 2008).

Teaching with and about modelling would thus not only promote a way of reasoning among students that is consistent with what scientists actually do but would also provide students with an opportunity to gain experience with a variety of legitimate methods of inquiry in science (Passmore, Stewart, & Cartier, 2009).

Transposing the practice of scientific modelling into science classrooms is not a straightforward process, however (Justi & Gilbert, 2002; Schwarz et al., 2009; Svoboda & Passmore, 2013). Some of the challenges in this regard relate to the way teachers tend to interpret and assimilate new concepts, teaching approaches and scientific practices introduced through reformed curriculum into their current familiar schemes (Lehrer & Schauble, 2015). In addition, it is well documented that teachers find it challenging to incorporate a competence-oriented approach into their teaching and assessment (Dolin et al., 2018; Nielsen & Nielsen, 2019; Nielsen et al., 2018). The concept of competence has also proved difficult to define and operationalize for teaching and assessment and thus hinders appropriate support for teachers on how to adopt the concept into their classroom practice (Dolin, Nielsen, & Tidemand, 2017; Nielsen, Dolin, & Tidemand, 2018; Rönnebeck et al., 2018).

Theoretical Framework

For the purpose of this paper, we define a model as an external representation used in science and science education that represents a target from the natural world (Oh & Oh, 2011). The target could be an object, a phenomenon, a process, an event, an idea and/or a system (Gilbert & Justi, 2016). The model may also appear in a variety of forms such as: symbols, physical models in 3D, animations, analogies, interactive simulations, kinaesthetic models, drawings and diagrams. As such, teaching for modelling competence ought to include different types of model and the knowledge about the natural world embedded in those models. While learning the science content knowledge embedded in different types of models constitutes an important part of teaching with and about models, it is not sufficient when teaching for modelling competence (Papaevripidou, Nicolaou, & Constantinou, 2014). Indeed, teaching aimed at developing students' modelling competence ought to entail students actively involved in the different aspects of modelling practices (Nielsen & Nielsen, 2019). Some aspects relate to the *functional roles* of models (e.g., describing, communicating, explaining and predicting) while others (e.g., designing, evaluating and revising) relate to the modelling process.

Inspired by Krell and Krüger's (2016) approach, we distinguish the functional roles of models as either using models *descriptively* as a means for describing, communication and explaining the target or using models *predictively* as hypothetical entities and research tools. In this way, we want to highlight the fact that the predictive use of models is a salient aspect to include in a competence-oriented approach to MoMo. Indeed, we would advocate giving the predictive function of models a key place in a competence-oriented approach to MoMo. For instance, the predictive function offers opportunities for envisaging alternative courses of future actions by changing a variable or adding a component to a model or predicting how a certain phenomenon could develop over time or in different situations for problem-solving purposes.

Scholars have argued that iterative cycles of *designing*, *evaluating* and *revising* models are an important part of fostering modelling competence (Crawford & Cullin, 2004; Miller & Kastens, 2017; Papaevripidou et al., 2014; Passmore et al., 2009; Schwarz et al., 2009). Likewise, involving students in the modelling process offers students the possibility of gaining a more authentic understanding of how models are used in science (Gouvea & Passmore, 2017). Indeed, and as argued by several scholars (e.g., Lehrer & Schauble, 2015; Passmore, Gouvea, & Giere, 2014) students' engagement with MoMo ought to resemble how scientists handle models for research and professional practice. An important part of how scientists handle MoMo relates to the relationship between empirical data and models. This includes how well a model explains or predicts data patterns and outcomes based on the iterative process of designing, evaluating and revising models (Passmore et al., 2009). As such, students' design, evaluation and revision of their own or others' models ought to include their own empirical data (Baek & Schwarz, 2015). Integrating the use of students' own data into the teaching would not only be in line with the way scientists use models but would also highlight the relationships between and among models, the target it represents, and data derived from the target - allowing the students to obtain a more advanced and reflective understanding of MoMo (cf. Krell et al., 2015). Indeed, teaching for modelling competence ought to entail meta-knowledge related to the nature of models as well as to the specific aspects of modelling practices in science (Schwarz et al., 2009). This knowledge includes the purpose, value, and utilization of models in society, education, and research (Lehrer & Schauble, 2015; Schwarz et al., 2009).

In sum, we acknowledge the importance of giving both (1) the science content knowledge embedded in different forms of models (*learning science*); (2) the different aspects of modelling practices (*learning to do science*); and (3) meta-knowledge about MoMo (*learning about science*) a central role in teaching for modelling competence. As indicated in the brackets above, addressing all three elements holds prospects for taking advance of the specific opportunities MoMo offers to facilitate students' learning with regard to each of Hodson's (2014) three main goals of science.

Science Teaching and Science Teachers in Denmark

Since the study reported here took place in a specific national context - that of the revised Danish science curriculum - this section also introduces some general structures related to science teaching in Denmark and some of the salient features of the reformed curriculum.

In Denmark, science is taught as an integrated subject (science and technology) from grades 1-6 (age 7-13) and as three separate subjects: biology, geography, and integrated chemistry/physics from grades 7-9. Danish science teachers normally have a Bachelor's teaching degree in Danish or Mathematics supplemented by 1-3 of the four science subjects noted above. Most Danish teachers consequently neither teach only science nor only one single science subject.

Danish lower-secondary science education was reformed with a new curriculum commencing in the school year 2015-2016 (Ministry of Education, 2014). The reform included curriculum statements and exam requirements as to what students should learn in terms of four main competences: investigation, modelling, communication, and contextualization. An additional subject-specific multiple-choice exam, mainly assessing content knowledge, was also introduced.

Aside from giving MoMo a more prominent position, the reformed curriculum also brought in a change from largely approaching models as products of knowledge that students should acquire towards a more process- and competence-oriented approach focused on students' engagement with different aspects of modelling practices such as designing, evaluating and revising models. While the nature of models was only related to visualizing something abstract, the revised curriculum also relates the nature and role of models to their function in scientific inquiry, such as adjustability to fit different purposes (Nielsen, 2018). In this way, the curricular revision not only entails an enhanced and new approach to MoMo but also a major change in how teachers are intended to approach scientific inquiry from a quite uniform step-by-step laboratory activity to a more diverse and dynamic process that includes modelling as a scientific practice.

In sum, the revised curriculum contains significant changes in terms of what and how teachers ought to treat models, modelling and scientific inquiry in the classroom. On top of this, the Danish teachers were also asked to add a complicated and poorly-defined competence-oriented approach to modelling (Nielsen, 2015; Rönnebeck et al., 2018). The introduction of so many major curriculum changes must clearly be a demanding task for teachers to implement.

Against this background, we set out to answer the following research question:

What characterizes teachers' perceived practices of, rationales behind, and possibilities for integrating models and modelling into their teaching in the light of a revised competence-oriented science curriculum?

METHODOLOGY AND PROCEDURE FOR ANALYSIS

Data were produced by means of an electronic questionnaire with multiple-choice questions, statements with five-point Likert-scale ratings and open-ended items. This study was conducted in spring 2018 and only considers teachers teaching in grades 7-9. To identify the participants for the questionnaire survey, we contacted the local school administrations of all schools in Denmark who teach science in grades 7 to 9 (n = 1,796 contacted schools). With one follow-up email, a total of 206 schools responded (11.5% response rate) providing a total of 718 science teachers' e-mail addresses (including 115 non-working e-mail addresses). The questionnaire was then distributed directly via the functioning e-mail addresses to 603 lower secondary science teachers. With one reminder after 7 weeks, 246 teachers employed at 153 different schools responded (40.8% response rate). The teachers who responded typically had a teaching degree in 0 (4%); 1 (43%); 2 (37%); 3 (14%); or 4 (2%) science subjects. Integrated chemistry/physics was the most common teaching degree (66%) followed by biology (53%), geography (28%), and science/technology (26%), respectively.

The participating teachers had different lengths of teaching experience in science: less than 5 years (17%); between 5 to 10 (25%), 11-20 (39%); and more than 20 (20%). Their years of teaching experience were similarly concentrated around specific subjects, with biology being the most common (76%) followed by chemistry/physics (70%), geography (65%) and science/technology (50%), respectively.

During questionnaire development, comments were made on the preliminary versions by representatives of various groups who we felt could contribute important different perspectives. These were: (a) 11 science teachers, (b) a key person in the development of the new curriculum at the Danish Ministry of Education, (c) a group of two science educators and one researcher from a central teacher training institution, and (d) six science education researchers. This feedback led to adjustments in the questionnaire, particularly related to the length, the formulations, the order of the questions, the terms used, and the number and wording in the Likert-scale ratings. This step was followed by a pilot test involving 34 science teachers on an in-service course. The pilot test only led to minor adjustments (new scale for in-service training, more options for additional education). The different people in the above groups (a-d) concurrently tested the questionnaire. According to the feedback we obtained, the wording and layout of a few items were refined. An overview of the main items and headings of the open-ended items in the questionnaire is provided in Appendix 1.

Separate approaches were used to analyze the quantitative (Likert-scale, multiple-choice) and qualitative (open-ended item) responses. Aside from descriptive statistics of the quantitative data (frequency, mean scores, standard deviations), the statistical analysis involved comparing scores to pairs of items within the same battery of Likert-scale items. For example, with regard to the six aspects of modelling practice we were interested in analyzing, whether teachers reported that they engage students in *designing own models* more frequently than engaging their students in *revising models*. The null-hypotheses for these cases are thus of the form 'for each possible pair of two aspects of practice, there is no difference between the reported frequencies of use for these two aspects.' A similar procedure was undertaken for the other item batteries. According to a Shapiro-Wilk Test (Razali & Wah, 2011), the scores for all variables from the questionnaire that were compared for significant differences were non-normal. The individual paired comparisons between scores of two items were therefore always done using the non-parametric Wilcoxon Signed-Rank Test (Rey & Neuhäuser, 2011).

The teachers' statements in the open-ended items were analyzed by means of bottom-up data-driven thematic analysis guided by Braun and Clarke's (2006) six-phase analytical tool for thematic analysis. This open and data-driven approach seems suitable for exploring teachers' statements since the purpose of including the open-ended item in the questionnaire was to give teachers the opportunity to elaborate on the pre-designed questions and allow them to share their views and experience. In this way, the analysis of the open-ended item statements was intended to elaborate and extend the Likert-scale and multiple-choice responses. The analysis of the latter likewise offers an opportunity for understanding the statements in the open-ended items.

In the presentations of the verbatim data from the questionnaires, each statement from an open-ended item is given an identifier - e.g., Q8 - and a number for the individual respondent - e.g., 542. In other words, Q8:542 marks respondent 542's response to the open-ended item related to item number eight.

RESULTS

This section presents the results from the analysis of the electronic questionnaires. The findings are ordered

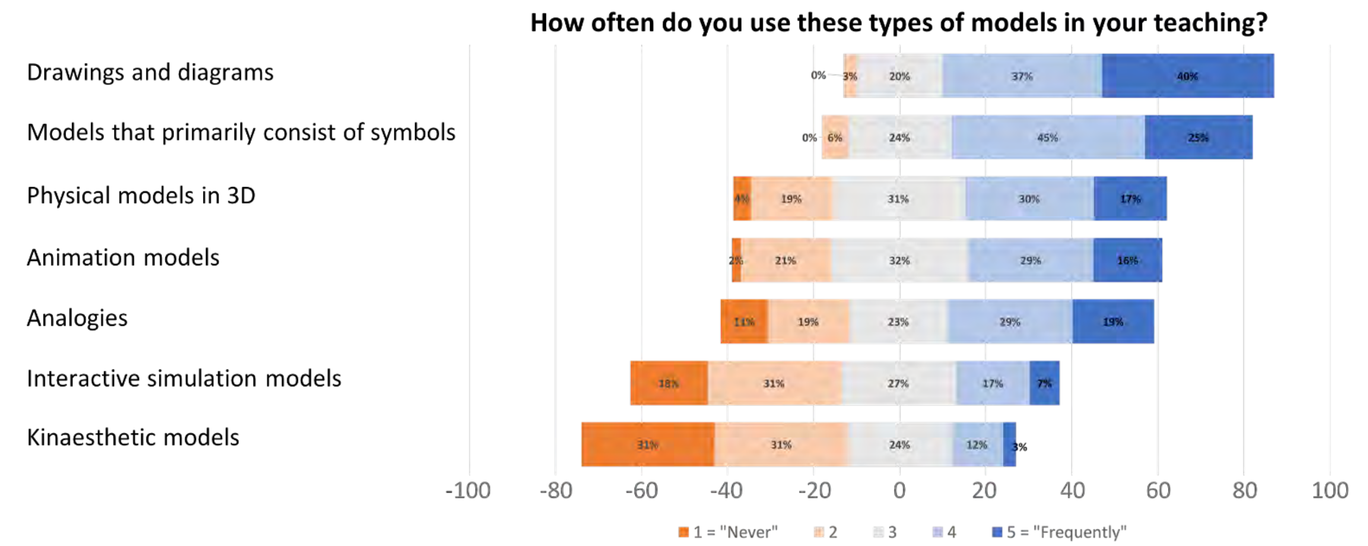

Figure 1. Diverging stacked bar chart of teachers' responses to how frequently teachers use six different types of models when models are part of the teaching (n = 238 teachers). Categories ranged from 'Never' to 'Frequently'. 'Frequently' was defined as 'almost every time models are used in your teaching'. Percentages are centered around the middle frequency category

Table 1. Mean values and standard deviations for the reported frequency of teachers' use of the six types of model as well as test statistics from non-parametric between-type comparisons (Wilcoxon Signed-Rank Test)

	Mean	SD	Models that primarily consist of symbols	Physical models in 3D	Animation models	Analogies	Interactive simulation models	Kinaesthetic models
Drawings and diagrams	4.1	0.9	Z= -3.6; p<0.001	Z= -8.2; p<0.001	Z= -8.7; p<0.001	Z= -8.4; p<0.001	Z= -12.0; p<0.001	Z= -12.7; p<0.001
Models that primarily consist of symbols	3.9	0.9		Z= -6.2; p<0.001	Z= -6.5; p<0.001	Z= -6.3; p<0.001	Z= -10.4; p<0.001	Z= -12.0; p<0.001
Physical models in 3D	3.4	1.1			Z= -0.1; p=0.904	Z= -0.9; p=0.394	Z= -7.2; p<0.001	Z= -10,2; p<0.001
Animation models	3.4	1.1				Z= -0.7 p=0.505	Z= -8.0; p<0.001	Z= -10.2; p<0.001
Analogies	3.3	1.3					Z= -6.1; p<0.001	Z= -9.2; p<0.001
Interactive simulation models	2.6	1.2						Z= -5.1; p<0.001
Kinaesthetic models	2.2	1.1						

according to six main areas: (1) Teachers' use of different model types; (2) Students' engagement with the different aspects of modelling practice; (3) Teachers' attention to the three overall learning goals for science education; (4) Teachers' acknowledgement of students' outcomes from specific modelling activities; (5) Teachers' perceived abilities to teach modelling as a competence; and (6) Teachers' possibilities for implementing a competence-oriented approach to MoMo.

Teachers' Use of Different Model Types in Their Teaching

Responses to the questionnaire (see Figure 1) indicate that although the participating teachers as a group used all the stated model types, not all the teachers used the whole range of types. Indeed, 18% and 31% of the teachers never use interactive and kinaesthetic models, respectively. Our findings likewise indicate that participating teachers used the different model types with varying frequency. And there is a pattern of significant differences between how frequently specific types are being used (see Table 1).

A Wilcoxon Signed-Rank Test was run to compare the median test ranks between all possible pairs of models used (see Table 1). The test indicated (a) that the scores for drawings/diagrams and symbols were significantly higher than the scores for all other model types, and (b) the scores for kinaesthetic and interactive simulations were significantly lower than the scores for all other model types. It is evident from these findings that the teachers report more frequently using the model types that traditionally play a role of visualizing or

Table 2. Examples from the open-ended item showing the different types of model used by the teachers

Type of model	Examples
Visual drawings and diagrams	Blackers' demographic transition model; Population pyramid; Food chains showing the relations between plants, herbivores, and carnivores; Carbon/Water/Nitrogen cycle; Mapping the schoolyard*; Graphs.
Symbolic	Photosynthesis represented as a chemical equation; Chemical equations; Periodic system; Topographical charts.
Material 3D	Globe; Plant cell; Molecular models*; DNA; Human organs; Torso; Bottle ecosystem; Miniature steam engine/turbine; Bohr model, Water cycle*.
Animations	Plate tectonics; Ozone absorbing and blocking UV radiation; Earth/Sun/Moon; Stop-motion protein synthesis movie*.
Analogy	An analogy for the enzymatic process in DNA transcription, based on a zipper.
Interactive simulations	Chemical processes; Natural selection; Induction.
Kinaesthetic*	Students holding each other's hands and pushing the current around by pressing hands, breaking the current when the connection breaks; Students modeling of day and night to experience the spinning Earth and the day/night cycle; Atomic bond; State of matter.

* Teachers' statements specified that the model was designed by the students

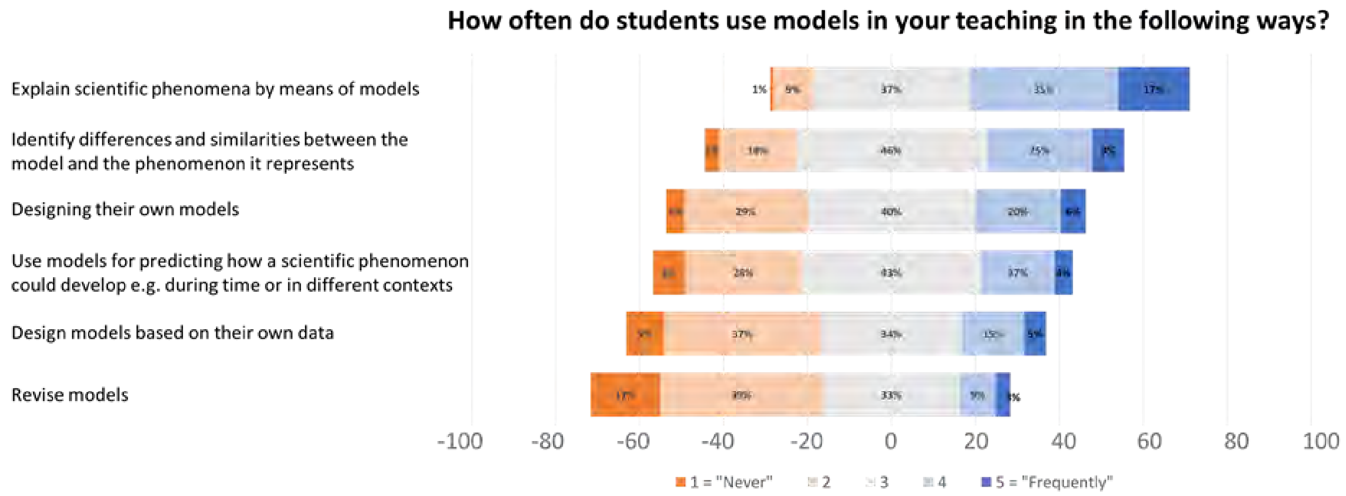

Figure 2. Diverging stacked bar chart of teachers' responses to how frequently students used six specific aspects of modelling practices when models were part of the teaching (n = 235 teachers). Categories ranged from 'Never' to 'Frequently'. Frequently was defined as 'almost every time models are used in your teaching'. Percentages are centered around the middle frequency category

making the subject-specific content knowledge from the curriculum concrete and/or are typically used in traditional textbooks. The teachers also - to a lesser extent - used model types that are interactive, and which often afford investigations of dynamic covariance - i.e. how different phenomena develop under changing circumstances.

In the corresponding open-ended item, some of the teachers (n = 34) provided concrete examples related to the model types and the content knowledge represented in the specific models used in their teaching (see Table 2). The examples all represented specific content knowledge from the curriculum; some examples contained models mentioned in the curriculum (Demographic Transition Model, Periodic Table), and/or model types and content knowledge often found in test materials (e.g., Food chains diagrams, 2D Carbon/Water/Nitrogen cycle, Photosynthesis represented as a chemical equation).

Teachers' Inclusion of the Different Aspects of Modelling Practice

The questionnaire data indicate that the participating teachers engage their students in the different aspects of modelling practice with varying frequency (see Figure 2), and that there is a pattern of significant differences between how frequently specific modelling practices are implemented (see Table 3).

The Wilcoxon Signed-Rank test indicated that the scores for 'explain scientific phenomena by means of models' were significantly higher than the scores for all other aspects of modelling practices. Overall, our findings thus suggest that teachers significantly prioritized the modelling practice of explaining over prediction, evaluation, design, and revision. This overall finding points to some more specific interesting characteristics related to how teachers prioritized students' engagement with different aspects of modelling practices.

Table 3. Mean values and standard deviations for the reported frequency with which students are engaged with six specific aspects of modelling practices as well as test statistics from non-parametric between-aspect comparisons (Wilcoxon Signed-Rank Test)

	Mean	SD	Identify differences and similarities between the model and the phenomenon it represents	Design their own models	Use models for predicting how a scientific phenomenon could develop, e.g., over time or in different contexts	Design models based on their own data	Revise models
Explain scientific phenomena by means of models	3.6	0.9	Z = -7.5; p<0.001	Z = -9.2; p<0.001	Z = -10.2; p<0.001	Z = -10.1; p<0.001	Z = -11.5; p<0.001
Identify differences and similarities between the model and the phenomenon it represents	3.2	0.9		Z = -3.5; p<0.001	Z = -5.5; p<0.001	Z = -6.3; p<0.001	Z = -9.4; p<0.001
Design their own models	2.9	1.0			Z = -1.9; p=0.054	Z = -3.9; p<0.001	Z = -8.0; p<0.001
Use models for predicting how a scientific phenomenon could develop, e.g., over time or in different contexts	2.8	1.0				Z = -2.0; p=0.42	Z = -6.4; p<0.001
Design models based on their own data	2.7	1.0					Z = -4.6; p<0.001
Revise models	2.4	1.0					

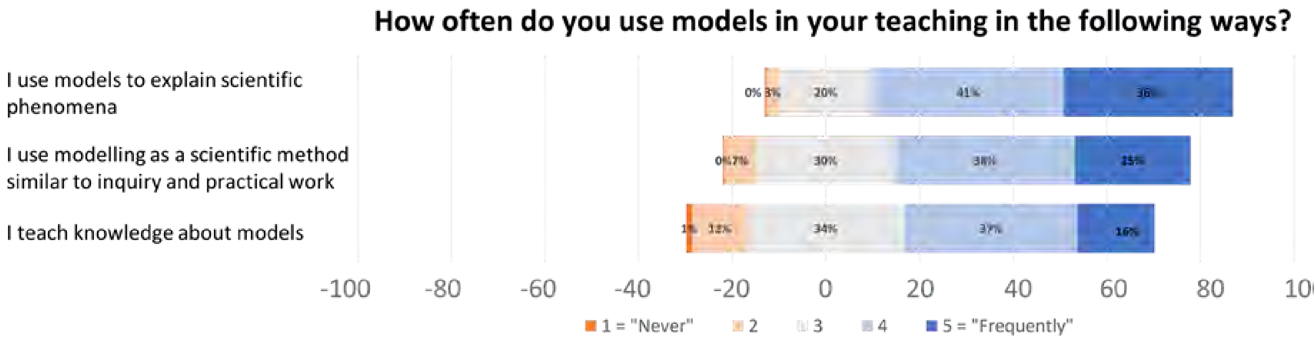

Figure 3. Diverging stacked bar chart of teachers' responses to how frequently they address the three overall learning goals of science education mentioned in the curriculum when they use models in their teaching (n = 238 teachers). Categories ranged from 'Never' to 'Frequently'. Frequently was defined as 'almost every time models are used in your teaching'. Percentages are centered around the middle frequency category

First, the findings show that when engaging students in different aspects of modelling practices, the teachers significantly prioritized the descriptive function of models over the predictive function.

Second, our findings suggest that even though design of models is perceived as a central part of modelling as a scientific process, students' engagement in designing their own models was relatively rarely implemented by some teachers, if at all (Figure 2). Students' design of models based on their own empirical data, in particular, seems to play a minor role in a relatively large part of the teachers' implementation of modelling activities. Indeed, the scores for 'design models based on students' own data' were significantly lower than all other types of modelling activities except for 'revising' (Table 3). Students design of models based on their own data was likewise indicated as being absent or rarely implemented by 9% and 37% of the teachers, respectively (Figure 2). While the Likert-scale item responses thus indicate that students' engagement in designing their own models was relatively rarely implemented, some teachers (n = 16) did provide examples in the open-ended item on models designed by students (see Table 2). Although some of these examples stated that the models were based on students' own inquiries (maps), the majority suggest that the students' design was based largely on given and established knowledge (Table 2). The responses from the Likert-scale, as well as the examples provided in the open-ended item, thus indicate that, for some teachers, students' design of models is only minimally related to their own empirical data. Our findings thus imply that students' own empirical data and the relationship between those data and model design only plays a minor role for a relatively large proportion of the teachers.

Third, our findings indicate that the evaluating practice of identify differences and similarities between the model and the target it represents is implemented by

Table 4. Mean values and standard deviations for the reported frequency in addressing the three overall learning goals of science education as well as test statistics from non-parametric between-goal comparisons (Wilcoxon Signed-Rank Test)

	Mean	SD	I use modelling as a scientific method similar to inquiry and practical work	I teach knowledge about models
I use models to explain scientific phenomena	4.1	0.8	Z = -5.6; p<0.001	Z = -8.5; p<0.001
I use modelling as a scientific method similar to inquiry and practical work	3.8	0.9		Z = -4.9; p<0.001
I teach knowledge about models	3.6	0.9		

almost all teachers and is found to be the second most common practice implemented in the classroom (Figure 2). Indeed, the scores for 'identify differences and similarities between the model and the phenomenon it represents' were significantly higher than all other types of modelling activities apart from 'explaining' (Table 3).

Finally, our findings suggest that students' engagement with modelling as a dynamic scientific process was only implemented to a limited extent by a majority of teachers. Indeed, teachers significantly prioritized students' explanations of models over engaging students in all three modelling aspects of designing, evaluating, and revising models (Table 3). Along the same line, it is notable that the scores for 'revising models' were significantly lower than the scores for all other aspects of modelling. Likewise, 17% of the teachers responded that they never engage students in revising models (Figure 2). Our findings thus indicate that the students' engagement in a modelling process that involves repeated cycles of designing, evaluating, and revising models is relatively rare and, for some teachers, never fully implemented.

Teachers' Attention to the Three Overall Learning Goals for Science Education

The responses from the questionnaire (see Figure 3) indicate that, in their teaching, the teachers addressed aspects related to each of the three overall learning goals of science education (*learning science*, *doing science* and *learning about science)* with varying frequency, and that there is a pattern of significant differences between how frequently the specific goals are addressed in their teaching (see Table 4).

A Wilcoxon Signed-Rank Test was run to compare the median test ranks between all possible pairs of learning goals addressed in teachers' teaching practice with and about models. Teachers significantly prioritized explaining scientific phenomena over 'using modelling as a scientific method' and 'including knowledge about models' in their teaching (see Table 4). They also significantly prioritized 'using modelling as a scientific method' over 'including knowledge about models' in their teaching.

Our questionnaire data therefore suggest that the teachers prioritized the following ranking in their teaching: subject-specific knowledge (learning science), modelling practices (doing science), and meta-knowledge (learning about science), respectively.

Teachers' Acknowledgement of Students' Outcomes from Specific Modelling Activities

This result relates to which potential learning outcomes the teachers identified for students' engagement with modelling. Overall, the teachers found that all the proposed justifications for the use of modelling were highly relevant (see Figure 4). Our data thus reflects teachers' acknowledgement of MoMo as a learning and motivation tool in their teaching.

A Wilcoxon Signed-Rank Test was run to compare the median test ranks between all possible pairs of affordances of using models (see Table 5). Teachers identify significantly more with outcomes that relate directly to science-content knowledge - that is, that models help to communicate scientific knowledge, understand causal relationships and contribute to the learning of concepts (learning science). They identified significantly less with outcomes related to working scientifically (learning to do science) and understanding how science contributes to knowledge production (learning about science).

The data thus suggest that teachers tend to see the affordance of integrating modelling into teaching as a way for students to learn the subject-content knowledge rather than to promote students' abilities to work with scientific methods in science or to support students' understanding of how science contributes to knowledge-generating in science.

Teachers' Perceived Abilities to Teach Modelling as a Competence

A large proportion of teachers stated that they agreed, or strongly agreed, that they were familiar with the concept of modelling competence in order to teach modelling as described in the curriculum, (78%; see Figure 5). While the data thus suggest that the majority of teachers generally felt confident in implementing modelling as a competence, it should be noted that the responses in relation to evaluating students' competences revealed a different pattern. Here, only 55% responded that they agreed, or strongly agreed, that

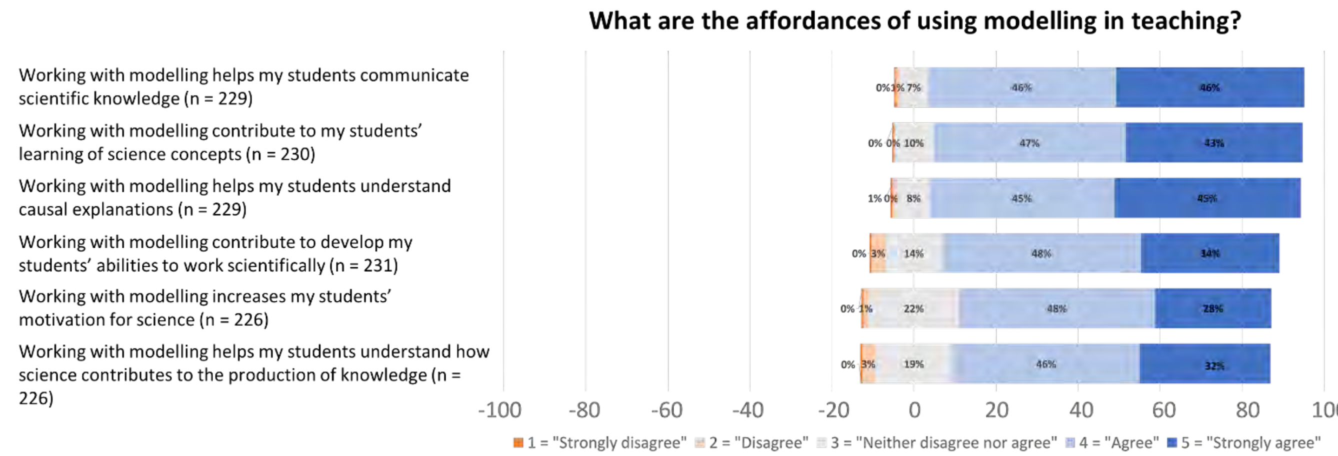

Figure 4. Diverging stacked bar chart of the level of teachers' agreement with whether or not using modelling has specific student-outcome affordances. Percentages are centered around the middle frequency category. 'Don't know' responses were excluded – the n-value thus varies

Table 5. Mean values and standard deviations for the level of teachers' agreement with statements on the effect of different types of student-outcome affordances when including models and modelling in their teaching as well as test statistics from non-parametric between-type comparisons (Wilcoxon Signed-Rank Test)

	Mean	SD	Working with models helps my students understand causal explanations	Working with models contributes to my students' learning of science concepts	Working with models contributes to developing my students' abilities to work scientifically	Working with models helps my students understand how science contributes to the production of knowledge	Working with models increases my students' motivation for science
Working with models helps my students communicate scientific knowledge	4.4	0.7	Z = -0.6 p=0.570 (n = 228)	Z = -1.2 p=0.226 (n = 228)	Z = -4.8; p<0.001 (n = 229)	Z = -5.5; p<0.001 (n = 224)	Z = -6.1; p<0.001 (n = 224)
Working with models helps my students understand causal explanations	4.3	0.7		Z = -0.5 p=0.591 (n = 228)	Z = -4.2; p<0.001 (n = 229)	Z = -5.1; p<0.001 (n = 225)	Z = -5.9; p<0.001 (n = 224)
Working with models contributes to my students' learning of science concepts	4.3	0.7			Z = -4.4; p<0.001 (n = 230)	Z = -4.8; p<0.001 (n = 225)	Z = -6.5; p<0.001 (n = 226)
Working with models contributes to developing my students' abilities to work scientifically	4.1	0.8				Z = -1.4 p=0.162 (n = 226)	Z = -2.3 p=0.022 (n = 226)
Working with models helps my students understand how science contributes to the production of knowledge	4.1	0.8					Z = -0.7 p=0.490 (n = 222)
Working with models increases my students' motivation for science	4.0	0.8					

they were capable of evaluating students' competences in modelling.

Teachers' Possibilities for Implementing a Competence-Oriented Approach to MoMo

This finding relates to how teachers were supported in, and how they perceived, their possibilities for implementing the curriculum intentions related to MoMo in their teaching.

The questionnaire responses showed that, in the three years since the new curriculum was implemented, 80% of the teachers had participated in less than 20 hours of science-related in-service training (see Figure 6). It is also notable that 42% of the teachers had not participated in any courses at all in this regard.

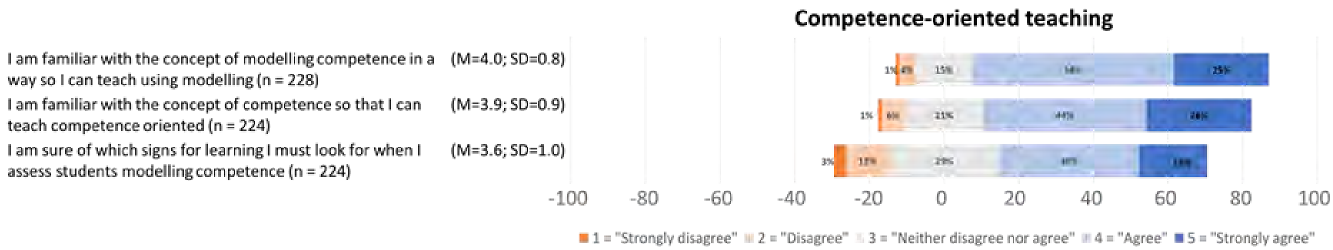

Figure 5. Diverging stacked bar chart of the level of teachers' agreement with statements about their ability to teach for (modelling) competence. Percentages are centered around the middle frequency category. 'Don't know' responses were excluded – the n-value thus varies

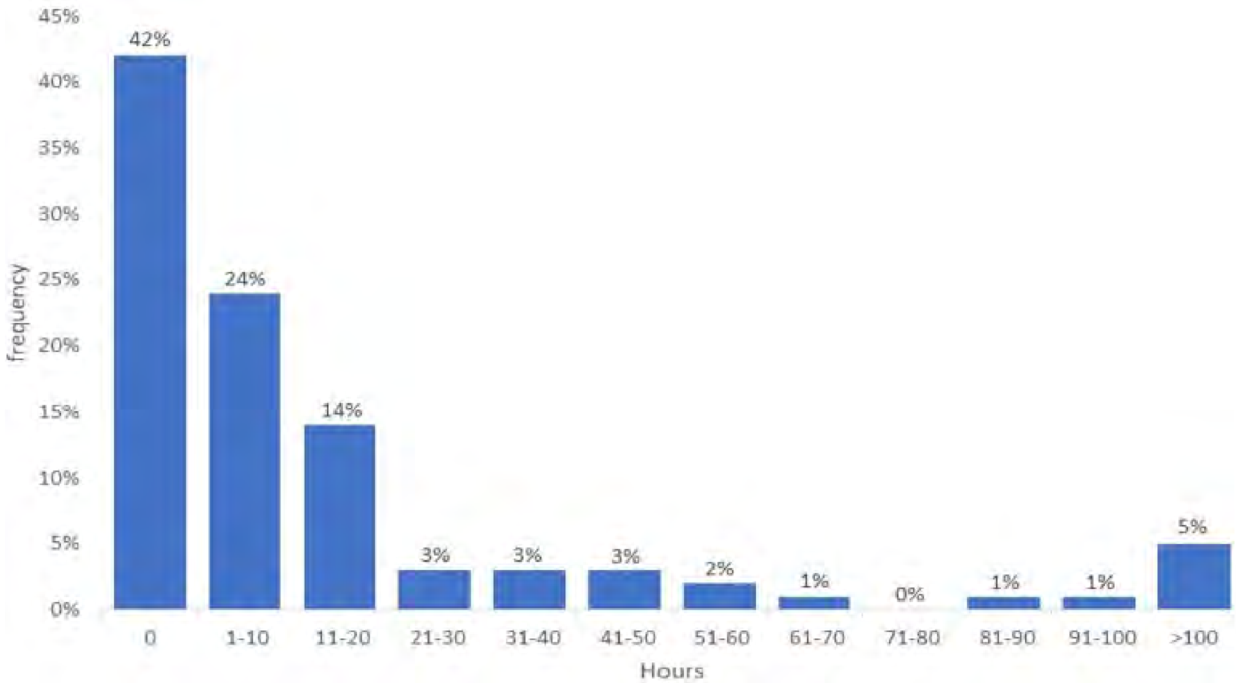

Figure 6. Frequency of the total number of hours of in-service training in science approved by the local school authority over the last three years (n = 246)

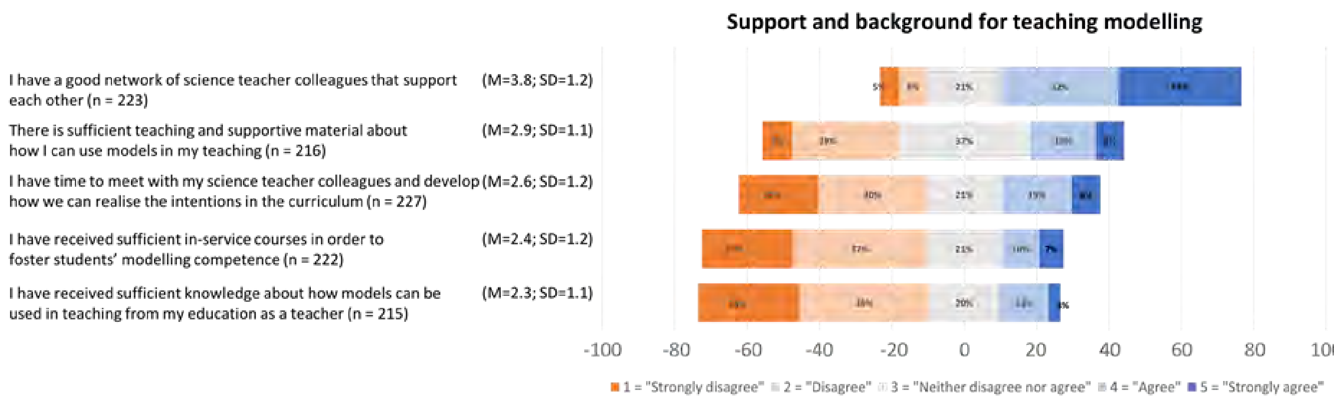

Figure 7. Diverging stacked bar chart of the level of teachers' agreement with statements about support and their background for teaching modelling as described in the curriculum. Percentages are centered around the middle frequency category. 'Don't know' responses were excluded – the n-value thus varies

Furthermore, only 17% of the teachers responded that they agreed or strongly agreed that they had participated in sufficient in-service training to integrate modelling into their teaching as a competence-based practice (see Figure 7).

It is also worth noting that only 16% of the teachers agreed, or strongly agreed, that they had obtained sufficient knowledge during their teacher training on how to integrate models into their teaching. In the same vein, one teacher described how the year they graduated influences their prospects for implementing the curriculum's new modelling requirements: "It takes a long time to understand the thoughts behind the curriculum, if you did not graduate recently" (Q12: 476). Although teachers perceived the implementation of the new challenges to be a challenging task, the open-ended item statements also indicated that there was progress, however: "Fortunately we are getting there, but it takes forever and a day" (Q12: 198).

More than half of the teachers disagreed, or strongly disagreed, with the statement: "I have time to meet with science colleagues to consider how to implement the intentions of the new curriculum" (see Figure 7). While the data therefore suggest that a quite large proportion of the teachers perceived meeting with colleagues as a challenge, the data also revealed that 64% of teachers agreed, or strongly agreed, with the statement: "I have a strong network of colleagues supporting each other" (see Figure 7). The open-ended item statements also reflected a high value and a high need and demand for better opportunities for sharing experiences, cooperative teaching preparation and evaluation. This point is illustrated in the following statements referring to the new curriculum: "There are so many good intentions […] but time is lacking…time for teaching, time for preparation, time for shared development and evaluation among my colleagues and in networks" (Q15: 453). Or, as stated by another teacher: "It has been impossible to meet this year […] we have up to 29 teaching hours […] it's really challenging to work like this […] It's so frustrating […] since we would so much like to develop this together" (Q15: 198). In general, the open-ended item statements relating to challenges and prospects for knowledge-sharing (n =14) were very long, detailed and, for some teachers, even emotional compared to other statements.

Other statements in the open-ended item directly expressed the insufficiency of the curriculum in relation to how MoMo could be implemented (n = 8). Some statements expressed general concerns such as: "Not much support offered with regard to modelling competence" (Q12: 719). Other statements related to a lack of clarification: "Too flimsy […] Too much focus on format instead of content" (Q12: 291) or, in the words of another teacher: "The concepts used in the curriculum are not always understandable for the teacher, and this makes it difficult to implement the intentions" (Q12: 476). The data therefore suggest that these teachers do not perceive the curriculum description as adequate support for transforming the intentions in the curriculum into teaching. It is notable that only 26% of the teachers (see Figure 7) responded that they agreed, or strongly agreed, that the current teaching and support materials on how to apply models in their teaching were sufficient. Indeed, some teachers indicated in the open-ended item that the existing material was considered inadequate: "With respect to working with models, the teaching material often seems superficial and approached from a very narrow/restricted perspective" (Q12: 208). In response to a lack of materials, some teachers developed their own: "Very limited materials on models […]. I make my own based on text and models from the Internet" (Q12: 448). Our data thus indicate that selected teachers perceived the curriculum description as inadequate to support their efforts in implementing its intentions, and a large proportion of them found there was a lack of adequate support materials in this regard.

In addition, a substantial number of statements in the open-ended item were directly related to a perceived lack of correspondence between the curriculum size and the teaching time (n = 19). For instance: "The number of teaching hours is the limiting factor to fulfilling the intentions in the curriculum. So much content to go through with only two biology lessons per week" (Q12: 120).

Another notable observation related to how the teachers seem to perceive the mismatch between teaching hours and external requirements as a limiting factor for a more inquiry and problem-based approach to their teaching: "We are asked to test the students, we need to go through the curriculum content, practice concepts, prepare for the exam […] and so there is rarely time for inquiry work with scientific phenomena and problem-based teaching" (Q12: 214). Or, as stated by another teacher: "With the few teaching hours we have, teaching becomes very theoretical, also because we need to make time for the new exam" (Q12: 576). It should be recalled that, aside from the competence-oriented exam, an additional subject-specific multiple-choice exam, mainly assessing content knowledge, was also introduced. As illustrated by the following statements, some teachers point to a lack of alignment between the competence-oriented and subject-specific exams. "Geography is tight, since students have to be prepared for the subject-specific and the interdisciplinary exams" (Q12: 185), and "It is so idiotic […] two different exams focusing on distinctly different capabilities […] there's no time to develop both" (Q12: 112). In this way, our findings suggest that, a combination of a content heavy curriculum and lack of alignment between two different external assessment approaches seems to be an obstacle for teachers in their efforts to implement a more competence-oriented and inquiry-based approach to MoMo.

Summary of Results

Our findings suggest that the participating teachers' perceived practices and rationales for integrating MoMo into their teaching were characterised by what we have called a product-oriented approach - that is, when responding to how and why MoMo were implemented in their classroom practice. Teachers tended to prioritize the product (i.e., the content knowledge embedded in models) over the modelling process and the knowledge of the process leading to the product. In addition, our findings indicate that, when modelling was implemented in the classroom, central aspects of the modelling process were treated in a very descriptive and restricted manner, with limited opportunities for reflecting an authentic picture of modelling as a scientific practice. Our data also indicate a difference between teachers' perception of their ability to teach modelling and their self-perceived implementation of modelling in their teaching. Finally, our findings suggest that, a combination of limited in-service training follow-up related to the reformed curriculum, inadequate opportunities for sharing knowledge among teachers, inadequate support materials, a mismatch between an overcrowded curriculum and teaching hours, and an exam format that largely assess content knowledge limit teachers' prospects for implementing the curriculum intentions of a teaching for modelling-competence.

DISCUSSION

Scholars have emphasized the need to give the three main learning goals of science education (i.e., learning science, doing science, learning about science) a more central and *equal* role in science teaching and improve the alignment between goals and classroom reality (Gouvea & Passmore, 2017; Hodson, 2014; Kind & Osborne, 2017). But our data suggest that the participating teachers primarily integrate MoMo for fostering learning of science-content knowledge (i.e., communicate scientific knowledge, understand causal relationships, learning concepts) and to a significantly lesser extend for fostering the skills and competences related to working scientifically or understanding how modelling contributes to knowledge production. The tendency to acknowledge the affordance of modelling related to students learning *the product of science* over and above *doing science* and *learning about science* was also reflected in our data on how frequently teachers addressed aspects related to each of the three learning goals in their teaching. Our data thus resonate well with former research among in-service and pre-service teachers, which show that the use of MoMo in teaching is largely implemented and justified by purposes related to students' learning of content knowledge (Campbell et al., 2015; Crawford & Cullin, 2004; Cullin & Crawford, 2002; Justi & Gilbert, 2002; Kahn, 2011; Miller & Kastens, 2018; Windschitl & Thompson, 2006).

Our findings also provided nuances related to how frequently aspects related to 'doing science' were implemented compared to aspects related to 'learning about science'. Indeed, 'doing science' was addressed more frequently compared to 'learning about science'. In line with other scholars (e.g., Justi & Gilbert, 2002; Van Der Valk, Van Driel & De Vos, 2007; Vo et al., 2015), we would hypothesise that this finding partly relates to teachers' limited knowledge of meta-knowledge related to the role of MoMo in science research. Indeed, we would claim that this relates particularly to the teachers in this study since experience in science research is not a part of teachers' education in Denmark. We find warrant for this hypothesis in our finding that only a minority of the respondents perceived their education as sufficient with respect to teaching MoMo.

A general theme in our data seems to be teachers rarely engage their students with important aspects of modelling as a scientific process. First, even though designing models is a central part of scientific modelling and therefore ought to be a central part of science teaching (Schwarz & White, 2005), students' design of models seems to play a minor role in classroom practice according to around one-third of the teachers. Students' design of models based on their own data, in particular, was rarely implemented for a large number of the teachers, if at all. Now, according to Schwarz and White (2005), one part of modelling is to develop models by embodying key aspects of theory *and data* into the model as well as evaluating and revising models to accommodate new theoretical *ideas or empirical findings*. In this light, teaching without linking students' empirical data and findings to model design, evaluation and revision would not give a full picture of modelling as a scientific process. Indeed, this kind of teaching would not only limits students' opportunities to participate in key parts of the science modelling process but also miss the opportunity to contribute to their understanding of the interaction between subject-specific knowledge, data and models.

In addition, it is difficult to see how teaching that only has limited opportunities for students to make explicit connections between their empirical findings and model design would support efforts to position modelling at the heart of scientific inquiry (Lehrer & Schauble, 2015). Modelling activities detached from students' empirical findings are likewise not well-suited to model‑based inquiry, as suggested as an alternative to the quite uniform step-by-step inquiry practice implemented in many classrooms (Passmore et al., 2009; Windschitl et al., 2008). We would furthermore claim that modelling without empirical data would miss the opportunity to develop students' abilities and awareness with respect to how models can facilitate and advance their use of other scientific practices, e.g., systematizing, interpreting and uncovering relationships in data (Lehrer & Schauble, 2015).

Second, students work with model revision seems to play a very limited role in the participating teachers' practice. This is also in line with previous findings (Kahn, 2011; Krell & Krüger, 2016; Van Driel & Verloop, 2002; Vo et al., 2015). The minimal use of revision suggests that students' engagement in the dynamic process of modelling, involving the often-repetitive cycle: design, evaluation and revision, was either lacking or very little prevalent in teachers' practice. As argued by Campbell and Oh (2015), modelling without revision would limit the prospects to afford students with a more comprehensive understanding of how models are developed and used in scientific research, including how models are used as knowledge-generating inquiry tools (Lehrer & Schauble, 2015). In a school context, revision could be based on additional evidence, new findings, students' advanced sensemaking, new theoretical aspects of the phenomenon or new applications (Gouvea & Passmore, 2017; Nielsen & Nielsen, 2019).

Further, students work to revise holds good prospects for addressing aspects of meta-knowledge (e.g., the tentative nature of models) in teaching. This also includes how revision could add to students' reflection by visualizing or displaying their learning progress (Schwarz et al, 2009). Indeed, this kind of meta-knowledge reflection is important in a teaching for modelling competence (Nielsen & Nielsen, 2019).

Our findings demonstrate that the participating teachers predominantly used model types (i.e., drawings, diagrams and symbolic) that are typically used in traditional textbooks and/or traditionally play a role in the curriculum and test materials. In contrast, the types of model (interactive simulations) that invite use in more predictive purposes were used only to a very limited extent. According to Gouvea and Passmore (2017), textbooks and curriculum materials mainly describe and position models as depictions of established knowledge, and this way of presenting models provides the wrong expression of the way MoMo are approached and used in scientific research, for example, as tools for predicting. Further, they argue that this way of presenting models encourages a descriptive use of models that focuses on students' reproduction or memorizing of the knowledge represented in the models.

In line with prior research (Khan, 2011; Van Driel & Verloop, 2002), our findings demonstrate that, when teachers engaged students in modelling activities, it was more often for descriptive than predictive purposes. Indeed, our findings resonate well with how MoMo are conventionally implemented in science teaching, curriculum and test materials (Gouvea & Passmore, 2017; Miller & Kastens, 2018; Van Der Valk et al., 2007). Our finding suggesting teachers' predominant engagement of students in a descriptive use of MoMo could therefore reflect the fact that not only do the teachers mainly use model types traditionally positioned as depictions of established knowledge but they also take up the same descriptive approach to models as positioned in the teaching and curricular material they use. As such, our findings correspond to Treagust, Chittleborough, and Mamiala's (2004) argument suggesting that the descriptive function must be considered as more obvious than the predictive for teachers to recognize and transform it into students' engagement with models.

Using models for predictive purposes is not only a salient aspect of scientific modelling (Baek & Schwarz, 2015; Krell & Krüger, 2016) but also ought to be an important aspect of students' involvement in modelling activities (Gouvea & Passmore, 2017; Van Driel & Verloop, 1999). The predictive nature and use of models are a similarly important aspect to include in a competence-oriented approach to MoMo (Krell & Krüger, 2016; Nielsen & Nielsen, 2019). Indeed, the predictive function plays an important role in students' work of applying and developing their knowledge through their active engagement in problem-based MoMo tasks such as predicting how a phenomenon will develop based on different actions or situations.

It is important, however, to note that, neither the predictive purposes of models nor the perception of models as hypothetical entities is explicitly mentioned in the Danish curriculum. This may partly explain the teachers' low frequency of engaging students in using models for predictive purposes. Another important observation relates to the way our data was collected. Since the questionnaire is based on teachers' self-perceived frequency, ranking our data would not capture teachers' often unconscious implementation of the predictive function and nature of models (Nielsen & Nielsen, 2019). While our data may therefore exclude teachers' unconscious use of models for predictive purposes, it also raises an issue related to how explicitly teacher implement MoMo in their teaching. Indeed, explicitly talking about the predictive nature and function of models is essential as it frames students' practice of modelling and adds to students' meta-modelling understanding (Gray & Rogan-Klyve, 2018). This kind of explicitness is clearly only possible if teachers are aware of whether, why, and when they engage students in activities related to models' predictive function.

According to Kind and Osborne (2017), a descriptive teaching approach largely provides students with lower-order cognitive challenges. Indeed, and in line with other scholars (e.g., Gouvea & Passmore, 2017; Treagust et al., 2004), we would claim that the predictive role, including using models as inquiry tools to test ideas, solve tasks and problems, is more advanced and reflective compared to a descriptive role that merely treats models as descriptions of what a phenomenon may look like and how it behaves. In this light, we would claim that the apparent low prevalence and implicit implementation of the predictive function of MoMo would not be in line with teaching for modelling competence.

As implied above, the participating teachers' approach to MoMo reflects the former curriculums descriptive approach to MoMo with only minimal opportunities for an applied and reflected use of models as inquiry tools. Indeed, our findings indicate that it is not a straightforward process for teachers to utilise the full range of opportunities for teaching for modelling competence in their implementation of MoMo (Nielsen & Nielsen, 2019), nor to give the three main learning goals of science education a more *equal* role in science teaching (Kind & Osborne, 2017), nor to use modelling as an enabler for a more diverse, authentic and advanced approach to inquiry than the step-by-step approach so often implemented in science teaching today (Lehrer & Schauble, 2015; Windschitl et al., 2008).

Implications

While our findings show critical areas for the continued development of teachers' practice in relation to teaching for modelling competence, our data also point to a number of potential actions that could be taken to further develop teachers' possibilities in this regard. As argued by Janssen et al. (2014), one concrete, attainable and sustainable strategy for facilitating teachers' implementation of new teaching approaches would be to extend their existing and valued practice. From this perspective, our findings demonstrate several areas of untapped potential for supporting teachers in their efforts to teach modelling competence. *First,* our findings suggest that the teachers perceived MoMo as a valuable learning and motivation tool in their teaching. *Second*, teachers' implementation of MoMo, albeit in a rather descriptive, restricted, and detached manner, addressed a wide range of those aspects of knowledge and practices that ought to be integrated into teaching for modelling competence. *Third*, the teachers stated that they had a strong and supportive network of science colleagues. Moreover, they wholeheartedly wished to further develop their teaching together as a group. One way to take advantage of this would be to organize and support school-based learning environments around teacher teams' planning related to their own existing and valued practice with MoMo. Indeed, our findings provide several opportunities where teaching could be extended to facilitate a more competence-oriented approach to MoMo. For instance, by extending model design to go beyond remediation of established knowledge by designing models based on students' own empirical data. Likewise, extending the use of revision by incorporating revision into students' evaluation of their own models with the use of new empirical data or advanced learning. Similarly, students' use and evaluation of multiple models could be used as an enabler for a less descriptive and more competence-oriented approach to MoMo. Indeed, multiple models offer opportunities for students to apply and reflect on how the selected features of different multiple models are useful for raising, answering, predicting, or solving specific tasks during a wide range of problem-based situations.

As indicated above, our findings demonstrate an untapped potential for extending teachers' practice towards a more competence-oriented approach to MoMo. However, our study also suggests a wide range of other issues that need to be properly addressed if teachers' prospects for teaching modelling competence are to be effectively enhanced: reworking the curriculum to match the number of teaching hours (or *vice versa*); ensuring better alignment between external tests and exams, and between external tests and curriculum intentions; reconsidering how to help teachers' understanding of the curriculum's intentions by clarifying concepts, providing examples and qualified supporting materials, and highlighting how MoMo can accomplish each of the three learning goals of science education equally; reconsidering how teacher education and in-service training can support teachers in the process from understanding to implementing a competence-oriented approach to MoMo, and recognizing that macro-level changes to curricula do not emerge in teaching by themselves unless substantial support and time is provided.

Limitations

One general limitation to the questionnaire method is whether the respondents understood all the questions as intended. While our questionnaire went through several rounds of field checks, some of the questions addressed quite extensive issues or included complex concepts. In this light, adding more questions in order to build scales that explore specific issues and teachers' understanding of the concepts would have improved the survey - both with respect to validation, comprehensibility, and the depth of the responses to the issues investigated. Another limitation related to whether the teachers' responses were honest. Danish teachers are often criticized in the public media. The teachers could therefore have responded to the questionnaire by painting a biased picture of doing as requested according to the curriculum. Efforts to avoid demonstrating limited competence would also be expected. Another limitation related to the way we recruited teachers to the questionnaire survey. Only 11.5% of schools responded, and we do not know whether the reason behind the local school administrators' choices influenced the nature of the teachers participating in the survey. We further do not know if the teachers who completed the questionnaire were particularly dedicated science teachers, particularly frustrated ones or something else.

Another important limitation of the study is that it was based on teachers' own perceptions of their teaching and understanding of MoMo. We do not know if these perceptions portray a 'true' picture of these teachers' practice nor to what degree, and how, teachers' understanding of MoMo influenced their response. Despite the above limitations, we still think our study enables us to identify some important patterns in Danish science teachers' practices, rationales, and possibilities for implementing teaching for modelling competence.

Unfortunately, our study and, to our knowledge, other studies do not provide information on why teachers prefer specific model types or how their choices of model influence the way they prioritize the different aspects of modelling. In this light, it is worth noticing that our data does not illuminate whether the teachers simply prefer to use drawings/diagrams/symbolic models rather than animations/interactive simulations or if the limited use of these model types is a result of a general lack of belief in using technologies or a result of other more general challenges encountered when incorporating new technologies into their teaching (e.g. limited availability of infrastructure, software, computer labs, lack of strategies, and/or perceived lack of time to prepare and incorporate technologies into teaching). Further research would be valuable in this regard. It would add to our understanding of the complexity and range of aspects that influence how teachers' handle MoMo in their teaching.

Author contributions: All authors have contributed to the study, and agreed with the results and conclusions.

Funding: The study is a part of the project "Facilitating Students' Learning from Inquiry and Practical Activities in Biology through Formative Assessments" funded by the Danish Ph.D.-Council for Educational Research.

Declaration of interest: No conflict of interest is declared by authors.

Acknowledgements: We wish to thank the participating teachers for donating their time and giving us the opportunity to add to our understanding of your teaching and rationales in this regard.

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APPENDIX 1

This appendix describes the main items and headings for the open-ended parts of the electronic questionnaire. The 'Q' numbers in brackets refer to the order of items throughout the entire questionnaire. Please note that the questionnaire also included three items (Q14 to Q16) not included in this study (e.g., teachers' assessment practice and their attitude to merging the current distinct science disciplinary subjects into one science subject).

The items directly targeting MoMo were placed at the start of the questionnaire and could be divided into seven subparts:

1. Teachers' background related to science teaching (prior education, in-service training, teaching experience in science and in specific science-disciplinary subjects, and scheduled science lessons per week) (Q1 to Q7).
2. Variety and frequency of teachers' use of different types/modes of models in their teaching (Q8), supplemented by information from the free statement box "*Please feel free to give more examples of specific models used in your teaching*".
3. Variety and frequency of the way teachers address the three different aspects of modelling competence (content knowledge, modelling practices, meta-knowledge) in their teaching (Q9), and teachers' opinions of the learning prospects in this regard (Q11).
4. Variety and frequency of students' active engagement with different aspects of modelling practices in teachers' teaching (Q10).
5. Teachers' perceptions of the prospects of implementing modelling as described in the current curriculum based on their self-perceived competences, support material, prior education, and specific school context issues (Q12), supplemented by information from the free statement box "*Please feel free to say if you have any comments regarding the extent to which it is possible to realize the intentions in the curriculum*".
6. Teachers' opinions about the relevance of bringing in the four new 'competence learning goals' and to what degree the introduction of the modelling competence goal has enhanced the focus on modelling in their teaching. This was supplemented by information from the free statement box "*Please feel free to comment on the questions*" (Q13).
7. Teachers' comments to the free statement box: "*Please feel free to provide additional comments related to the questionnaire*" (Q17).

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