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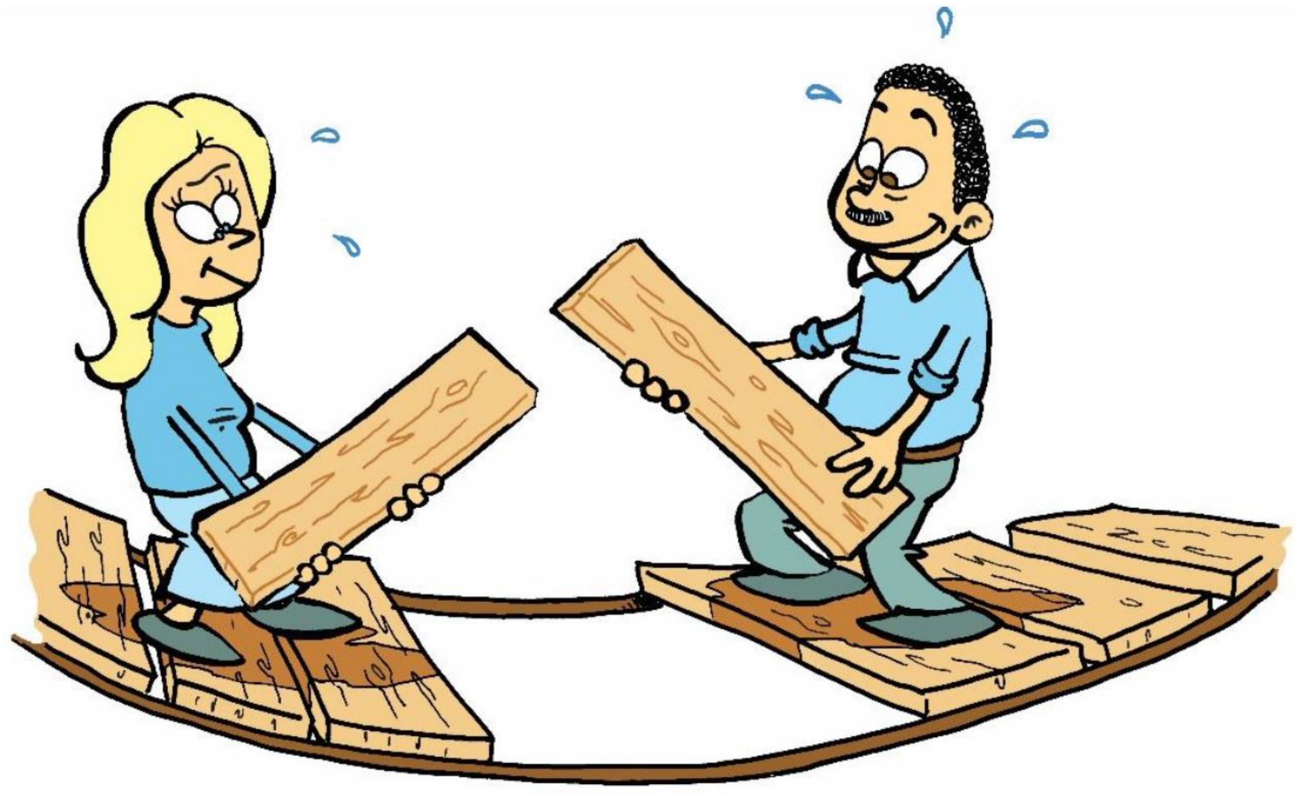

Teaching for Modelling Competence

- Expanding the scientific basis for bridging the gap between teachers' practices and political intentions in the realization of a modelling-oriented science curriculum in Danish lower secondary school

PHD THESIS
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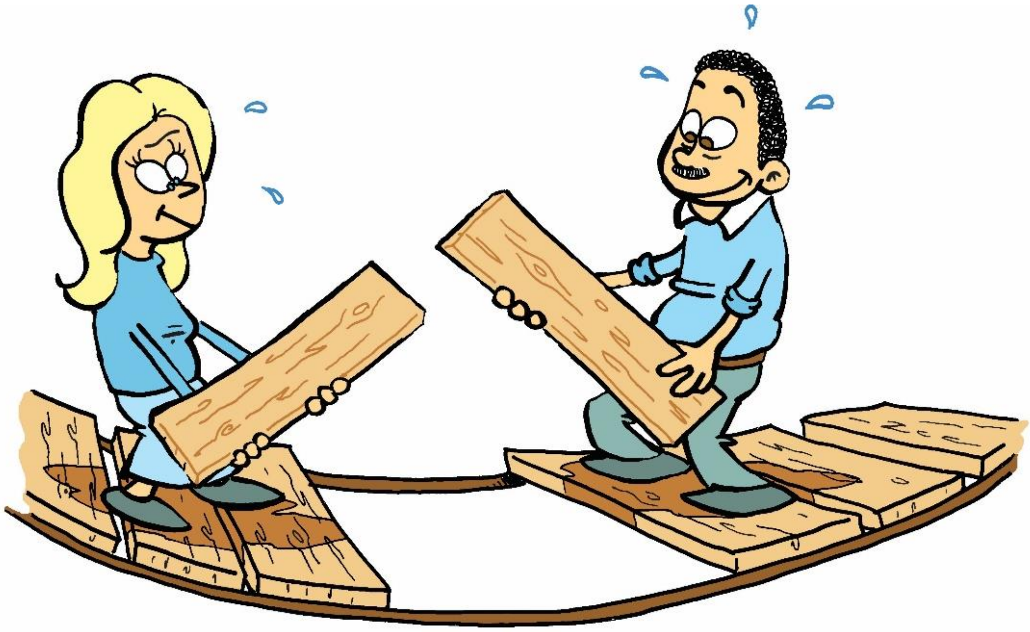
Sanne Schnell Nielsen



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Content

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Abstracts

In English

Danish lower secondary science education was reformed with a new curriculum commencing in the school year 2015-2016. The new curriculum led to substantial changes in how teachers should address models, modelling and scientific inquiry in their teaching. The purpose of this Ph.D. study is to analyse the alignment between the intentions and arguments for integrating models and modelling into science education, on the one hand, and teachers' practices and rationales for integrating models and modelling into their teaching practice, on the other.

First, this study analysed the new and the previous curriculum in aiming to explore the challenges and possibilities of the curriculum as an enabler of teaching for modelling competence. Second, a theoretical competence-oriented modelling framework was outlined. This framework describes what kind of knowledge and practice related to models and modelling that needs to be integrated into teaching to accomplish a competence-oriented approach in this regard. Third, teachers' practices of, rationales behind, and perceived possibilities for realizing the intentions of the reformed curriculum were investigated using a mixed-method approach. Data for this empirical part of the study was generated by means of a questionnaire survey (n = 246) and audio recordings of teachers' talk-in-interaction (n = 6; in three pairs) during two kinds of session: (a) reflections on their existing practices framed as explorative semi-structured interviews, and (b) discussions about their future teaching framed as workshops. In addition, the descriptions of the teaching activities, learning goals and rubrics developed during the workshops were collected. The competence-oriented modelling framework was used as the backdrop for the analysis of the empirical data.

The analysis of the curriculum identified significant challenges in the format and content with regard to supporting teachers' interpretation, understanding and transformation of the intentions into a teaching for modelling competence. The analysis of the empirical data suggested that teachers have a positive attitude towards the modelling emphasis in the new curriculum, and that models play an important and valued role in their teaching. The findings also suggested that teachers' practice and rationales for integrating models and modelling into their teaching are characterized by a product-oriented approach that is not well aligned with a competence-oriented teaching. The study not only indicates a gap in the alignment between curricular intentions and theory on teaching for modelling competence on the one hand, and teachers' practice and rationales on the other, but it also suggests that to narrow this gap, efforts are needed on both sides. The study provides multiple ideas for improving the alignment, based on opportunities and challenges on each side.

In Danish

Grundskolens lærere skal med jævne mellemrum forholde sig til og gennemføre nye reformer og tiltag. I forbindelse med en ny folkeskolereform har naturfagslærerne i udskolingen fra starten af skoleåret 2015/16 skulle implementere en revideret udgave af det tidligere curriculum 'Fælles Mål'. I det tidligere curriculum var modeller kun nævnt sporadisk. Desuden var der en vægtning af eksperimenter og feltundersøgelser som repræsentanter for de naturvidenskabelige arbejdsmetoder. En vigtig forskel mellem det tidligere curriculum og den reviderede udgave er et generelt øget fokus på brug af modeller i undervisningen. En anden central ændring er indførelsen af en kompetence-orienteret tilgang til begrebet modellering, en tilgang som afspejler vigtige aspekter af de naturvidenskabelige arbejdsmetoder. Denne tilgang til naturfagene er ny for naturfagslærerne. Der ligger derfor en udfordring i både at forstå de nye intentioner og at omsætte dem til en undervisningspraksis, der giver mening og er gennemførlig i en grundskoleskole sammenhæng.

Formålet med denne Ph.D. afhandling er at analysere forholdet mellem *på den ene side* lærernes undervisningspraksis med modeller og modellering og deres rationale herfor - og *på den anden side* intentionerne i curriculum og den forskningsbaserede teoretiske forståelse af en kompetence-orienteret tilgang til modeller og modellering.

Første del af projektet omfatter en analyse af det tidligere og det nye curriculum med henblik på at kortlægge forskellene mellem de to curricula og for at klarlægge de udfordringer og muligheder, som revideringen har medført i forhold til at kunne omsætte intentionerne til en undervisnings-praksis, der kan udvikle elevernes kompetencer til at arbejde med modeller og modellering. I anden del af projektet foreslås en teoretisk ramme for, hvordan begrebet modelleringskompetence kan forstås og omsættes til undervisningspraksis i grundskolens naturfagsundervisning.

Tredje del af projektet er et 'mixed-metode' studium. Til den empiriske del af dette blev data indsamlet elektronisk ved hjælp af spørgeskemaer til et antal lærere (n = 246) og ved hjælp af en skolebaseret undersøgelse med seks naturfagslærere, der er ansat på tre forskellige folkeskoler. Sidstnævnte var bygget op omkring to forskellige typer af 'talk-in-interaction' sessioner med et lærer-par på hver skole: a) semi-strukturerede interviews rammesat som refleksionssessioner relateret til lærernes eksisterende undervisningspraksis med modeller og modellering, og (b) workshops-sessioner relateret til lærernes planlægning af deres kommende undervisning. Lyden fra lærernes 'talk-in-interaction' blev optaget, og lærernes undervisningsmateriale i form af læringsmål, elevaktiviteter og rubrikker med progressionsopdelte læringsmål blev indsamlet.

Analysen af curricula viser, at der er væsentlige udfordringer både i format og indhold i forhold til at kunne understøtte lærerne i deres fortolkning og forståelse af intentionerne i curriculum – og dermed støtte lærerne i deres arbejde med at operationalisere intentionerne til en kvalificeret undervisning, som kan bidrage til at udvikle elevernes modelleringskompetence. Analysen af de empiriske data peger på, at lærerne har en positiv holdning til det øgede fokus på modellering i det nye curriculum, og at modeller spiller en central og værdsat rolle i deres undervisningspraksis. Resultaterne viser imidlertid, at lærerne generelt, både i deres rationale og i deres praksis, har en produkt-orienteret tilgang til modeller og modellering, som kun i begrænset omfang afspejler de centrale aspekter af en kompetence-orienteret tilgang til modeller og modellering. Der er en betydelig afstand mellem lærernes rationale/praksis - og intentionerne i curriculum og den forskningsbaserede teoretiske forståelse af en kompetence-orienteret tilgang til modeller og modellering. Afslutningsvis foreslås en række konkrete forslag til forandringstiltag, som er baseret på de muligheder og udfordringer, som projektet har afdækket.

1. Introduction[1]

Danish lower secondary science education was reformed with a new curriculum commencing in the school year 2015-2016 (Ministry of Education, 2014a). Like in other countries, the former curriculum prioritized students' learning of content knowledge, separating skills and content knowledge, and did merely perceive the scientific inquiry and students' scientific thinking as a matter of laboratory and field work (Kind & Osborne, 2017; Ministry of Education, 2009). The new curriculum led to substantial changes in how science teachers should address models, modelling and scientific inquiry in their teaching (Nielsen, 2015; Nielsen, 2017). Most importantly, there was a change from mainly approaching models as products of knowledge that students should acquire to a more competence-oriented approach focusing on students' engagement with different aspects of modelling practices such as designing, evaluating and revising models (Ministry of Education, 2014b).

1.1 Models and modelling in science education

Models play a central role in science. It could be argued that the process of modelling is *the* core practice in science[2] (Lehrer & Schauble, 2015; Passmore, Gouvea & Giere, 2014). Moreover, several scholars have pointed to the affordance of modelling in terms of facilitating students' learning of science concepts, the acquisition of scientific reasoning processes, and a strengthening awareness of how science works (Baek & Schwarz, 2015; Campbell & Oh, 2015; Gilbert & Justi, 2016; Nicolaou & Constantinou, 2014). The above mentioned affordances of modelling in facilitating students' learning corresponds well with three of Hodsons' (2014) four learning goals for science education (learning science, doing science, learning about science).

However, modelling is a complex process. Likewise, translating scientific modelling into science classrooms is not a straightforward process (Justi & Gilbert, 2002a; Schwarz et al., 2009; Svoboda & Passmore, 2013), and previous research has documented that a qualified use of models and modelling is not a widespread practice in science teaching (Khan, 2011; Krell & Krüger, 2016; Miller & Kastens, 2018; Schwarz et al., 2009). In particular, teachers' use of teaching practices that engage students in the process of modelling seems to play a minor role compared to teachers' prioritisation of the content knowledge of the models (Campbell et al. 2015; Justi & Gilbert, 2002b; Miller & Kastens, 2018). Likewise, the epistemological aspects only take a minor role in the way teachers enact and acknowledge models and modelling (Miller & Kastens, 2018; Vo et al., 2015; Windschitl et al., 2008).

Previous research suggest that some of the challenges in enacting a new modelling-oriented curriculum relate to teachers' limited and often inconsistent knowledge of models, and what modelling as a process in science entails (Justi & Gilbert 2002a,b, 2003; Justi & van Driel, 2005; Krell & Krüger, 2016, Schwarz & White, 2005; Van Driel & Verloop, 1999; Vo et al., 2015). In the same line, the enactment of modelling in classrooms is highly influenced by the way teachers understand scientific inquiry – namely as a self-contained procedure, only nominally linked to content knowledge, and represented by the universal scientific method (Windschitl et al., 2008). Other studies have reported that different teachers hold rather different ideas about models and modelling in science and enact the use of models quite differently (Khan, 2011; Krell & Krüger,

[1] This short part of my thesis is based on the more detailed background sections in paper 2, 3 and 4. Content, sentences, wording and references will therefore sometimes be identical between this section and the papers.

[2] The subject of this thesis is models expressed as external artefacts (Gilbert & Justi, 2016) and the noun 'model' is perceived as the product of a scientific process, and the verb 'modelling' as a scientific process (Baek & Schwarz, 2015).

2016; Van Driel & Verloop, 1999, 2002; Vo et al., 2015). Likewise, research suggests that experience and routine are needed for enacting a qualified application of modelling into teaching (Krell & Krüger, 2016; Schwarz & Gwekwerere, 2007).

Another challenge related to teachers' qualified application of models and modelling into their teaching is that the prominent role of modelling in science education curricula often is embedded in a substantial shift towards *competence-oriented curricula* in many countries (Ananiadou & Claro, 2009; Crujeiras & Jiménez-Aleixandre, 2013) – in particular in Denmark, where modelling *competence* is now one of four transversal competence goals for all science subjects in Danish primary and lower secondary school (Ministry of Education, 2014a). The introduction of competence-based curricula is being used as part of strategic planning for educational change across Scandinavian, and in many European, countries (Rasmussen, 2013). Lehrer and Schauble (2015) argue that the lack of coherence between curriculum intentions and teachers' practices is partly because teachers tend to interpret and assimilate new curriculum requirements and concepts into their current familiar schemes. Likewise, teachers' understanding of what the concept of modelling entails is crucial for what and how the concept from the curriculum is adopted into their teaching (Justi & van Driel, 2005; Schwarz & White, 2005; Vo et al., 2015). Not only is the term 'modelling' still conceptually ill-defined and scholars have called for clarification (Campbell et al., 2015; Gilbert & Justi, 2016; Nicolaou & Constantinou, 2014; Nielsen, 2015), the concept of competence is also still a topic of ongoing debate in science education (Ropohl et al., 2018; Rönnebeck et al., 2018).

It is not straightforward for teachers to translate the complex process of scientific modelling into their science classrooms (e.g. Svoboda & Passmore, 2013), nor to change the way the teachers perceive the process of scientific inquiry (Windschitl et al., 2008) and school science (Miller & Kastens, 2018), nor to shift teachers from undertaking a product-oriented approach towards undertaking a competence-oriented approach in their science teaching (Nielsen & Dolin, 2016; Sølberg, Bundsgaard & Højgaard, 2015). Indeed, it must be considered a tall order in that not only are models and modelling very complex concepts (Schwarz et al. 2009) but, on top of this, Danish science teachers are also being requested to add a complicated and poorly defined competence-oriented approach to their teaching (Ropohl et al., 2018). In this light, and given Danish school teachers' novelty of teaching for modelling competence, it must be a daunting task for Danish teachers to change their practice to align with the competence-oriented intentions related to modelling in the new curriculum.

1.2 The aim of the Ph.D. project

This Ph.D. project seeks to elucidate what science teachers are doing when they adopt the intended curriculum to teach for modelling competence, as well as their rationales for doing what they are doing. The intention is to document and understand the alignment between teachers' practices, rationales and possibilities for integrating models and modelling into teaching, on the one hand, and the theoretical and political intentions, on the other. The assumption is that the alignment and tensions significantly affect the possibilities and challenges for teachers to enact modelling as a competence-oriented, meaningful and manageable teaching practice. The overall aim of my project is to contribute knowledge from a teachers' perspective on how to narrow the gap between curriculum intentions and teachers' practice with regard to integrating a competence-oriented approach to models and modelling into science teaching in lower secondary school in Denmark (Figure 1.1).

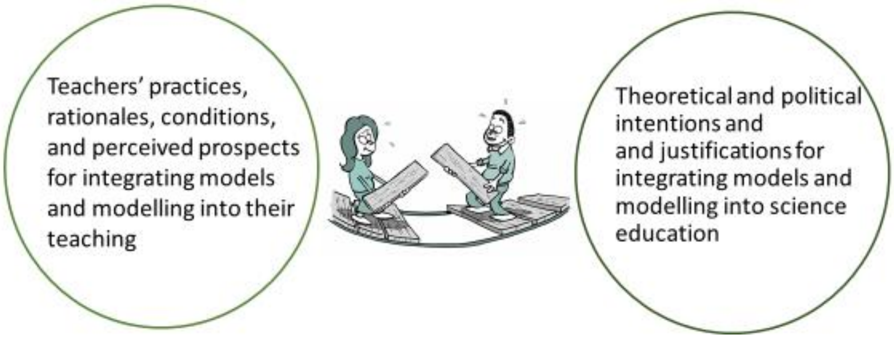

Figure 1.1 The overall aim of this Ph.D. project is to contribute knowledge from a teachers' perspective on how to narrow the gap between curriculum intentions and teachers' practice with regard to teaching for modelling competence.

1.3 Research questions

The aim of this Ph.D. project is operationalized through the following research questions:

a) *What characterizes Danish science teachers' practices and rationales for integrating models and modelling into their teaching and how is this aligned with a competence-oriented teaching approach to models and modelling? (Paper 3 and 4)*

b) *What are the possibilities and challenges for teachers when adopting a curriculum based on a competence-oriented approach to models and modelling? (Paper 1, 2, 3 and 4)*

2. Towards a framework for modelling competence[3]

In this section, I will suggest and argue for the construction of a 'modelling competence framework'. The framework describes those aspects of knowledge and practice that ought to be integrated into teaching to facilitate students' competences in modelling as a way of accomplishing three of Hodsons' (2014) four main learning goals of science education (i.e. learning science, doing science, learning about science).

2.1 Purposes of the framework in the Ph.D. project and beyond

My suggested framework serves several purposes in this Ph.D. project and beyond. *First*, the framework contributes to the much-needed and ongoing efforts in educational research to clarify an operational approach to modelling as a competence in teaching in order to accomplish the overall learning goals for science education. Although work has been done in the past to define modelling as a competence, the term 'modelling' is still conceptually ill-defined and scholars have called for clarification (Campbell et al., 2015; Gilbert & Justi, 2016; Nicolaou & Constantinou, 2014). Scholars have likewise emphasized the need to give the learning goals of science education a more central role in science teaching and improve the alignment between the goals and classroom reality (Kind & Osborne, 2017). In this light, I hope my proposed framework will contribute to the much-needed and ongoing efforts in educational research to clarify modelling as a competence in science teaching. *Second*, the framework will make my theoretical position in my Ph.D. project transparent. *Third*, the framework will be used as a backdrop for my empirical analysis of teachers' practices and rationales for integrating models and modelling into their teaching. *Fourth*, the framework is used to explore and reflect on how to operationalize teaching for modelling competence at the classroom level based on the empirical findings. *Finally*, the framework will be used to discuss the implications of how to enhance teachers' possibilities for teaching for modelling competence.

2.2 Outline of the guiding principles behind the framework construct

Before entering into more detail about how the framework was constructed, I will briefly outline how the above-mentioned purposes guided the development and use of the framework in this project. First, I formulated the framework by taking into account the intentions (the *what* and *how* to teach) and their justification (the *why* to teach) based on information from international science education research and the Danish science curriculum[4]. I thus aimed to ensure that the framework was (a) theoretically grounded in existing educational research, and (b) took into account the policy intentions reflected in the Danish curriculum. To shed light on and discuss how the framework could be enacted from a classroom perspective, the framework was used for analyzing teachers' teaching and their rationales in this regard (see section 4.6 for more information). I thus aimed to ensure that teachers' understanding, rationale and ways of enacting modelling and models were taken into account in my consideration of how to narrow the gap between curricular and theoretical intentions and teachers' practices. The construction and use of the framework are illustrated in Figure 2.1.

[3] This section serves to elaborate on the rather short description of the construct of the framework provided in paper 3. content, sentences, wording and references will therefore be identical between this section and the paper.

[4] In the reformed curriculum, modelling competence is a crosscutting goal that runs across the three science disciplines of geography, biology and physics/chemistry in lower secondary education.

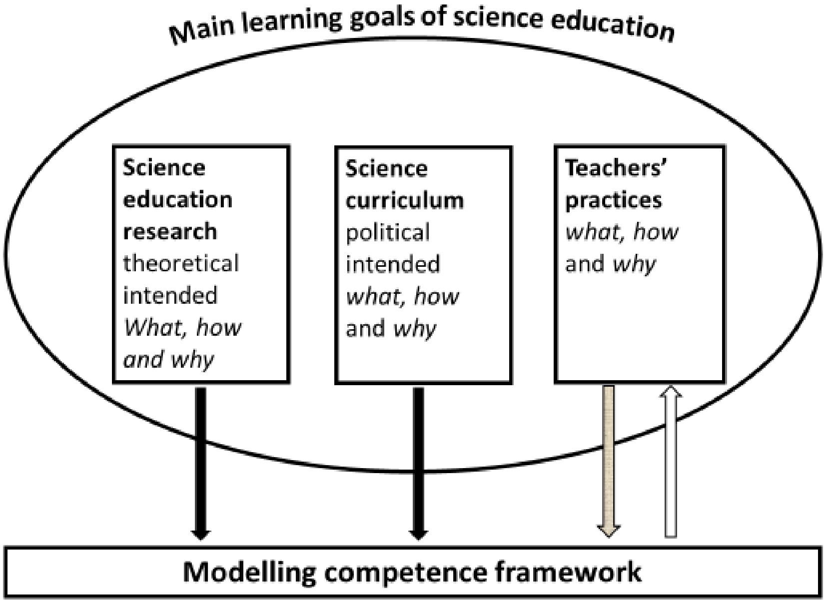

Figure 2.1 The construction and use of the modelling competence framework. The sources used to construct the framework are represented by science education research and the science curriculum. The source to suggest how the framework could be enacted from a classroom perspective is represented by the teachers' practices. The solid arrows indicate the sources used in constructing the framework. The white arrow indicates how the framework was used to analyze teachers' practices. The shaded arrow indicates that the framework could be operationalized at the classroom level based on new perspectives obtained from the analysis of teachers' practices and their rationales in this regard. The circle indicates how the main learning goals of science education framed the relevance of aspects from the different sources to be used to inform the construction and suggested realization of the framework.

In the next section, I will describe and justify why my suggested framework was based on science educational research and the political intentions as reflected in the Danish curriculum.

2.3 Towards the construct of a modelling competence framework

In this section, I suggest a framework for a competence-oriented approach to models and modelling that describes the relevant aspects of knowledge and practices that ought to be integrated into teaching in order to facilitate students' competences in modelling as a way of accomplishing the main learning goals of science education. The framework's development took account of the intentions (the *what* and *how* to teach) and their justification (the *why* to teach) from two sources: the Danish curriculum and international science education research. See Figure 2.1.

This construct ensured that my framework includes both the political intentions in Denmark and the theoretically important aspects of modelling competence. First, I will outline how the main elements of my framework were informed by science educational research more generally. Second, I will elaborate on how models and modelling are approached in the curriculum. Finally, I will go into greater detail about each of the main elements of the framework based on educational research and the curriculum.

There have previously been some efforts in educational research to describe modelling as a competence (Grünkorn, Upmeier zu Belzen, & Krüger, 2014; Krüger, Krell, & Upmeier zu Belzen 2017; Nicolaou & Constantinou, 2014; Papaevripidou, Nicolaou, & Constantinou, 2014). In addition, scholars have suggested descriptions of how to approach modelling as an epistemic practice (Campbell & Oh 2015; Gouvea & Passmore 2017; Lehrer & Schauble 2015) and an inquiry practice in science education (Cullin & Crawford 2002; Passmore, Stewart, & Cartier 2009; Schwarz et al. 2009; Schwarz & White, 2005; Windschitl & Thompson 2006). These approaches to modelling as a practice are similar but not identical to competence-oriented descriptions of modelling, and Schwarz & White's (2005) approach to modelling is treated as a competence elsewhere (i.e. Nicolaou & Constantinou 2014). The 'practice of modelling' construct could, for this reason, be perceived as being aligned with a competence-oriented approach to models and modelling. Based on this perception, I used scholars' descriptions of the 'practice of modelling' to inform the construct of the framework together with the above-mentioned efforts to describe modelling as a competence.

Although termed, prioritized and structured differently, the above research literature points to two main elements that should be included in my competence-oriented framework. The first element relates to what I call *different aspects of modelling practice*, which provides an *action* dimension and is therefore a core element of a competence-oriented approach to models and modelling (c.f. Busch, Elf & Horst, 2004). The second element is what I call *meta-knowledge of models and modelling*. This meta-knowledge element provides a *reflective* dimension related to enacting the different aspects of modelling and is therefore also a core element to be included in a competence-oriented framework (c.f. Nielsen & Gottschau, 2005). In addition to these two elements, I propose a third element for inclusion in the framework that relates to the *subject-specific knowledge* represented in specific models. I justify this third element in more detail below.

I will now elaborate on how models and modelling are approached in the curriculum. In the curriculum, students' explanation of the subject-specific knowledge represented in the model takes a predominant position (Nielsen, 2018). In addition to students' use of models for *explanation*, the curriculum outlines five further modelling practices related to students' engagements with models: *evaluating*, *comparing*, *selecting*, *designing* and *revising* (Ministry of Education, 2014b). The curriculum's intentions thus cover how to engage students in six specific *aspects of modelling practice*. All practices are solely related to the models' explanatory and representational power (Nielsen, 2018). In addition, the curriculum (although formulated rather superficially) also contains the following requirements related to students' *meta-knowledge* of models: *nature of models*, *merits and limitations of models*, different *models serve different purposes*, and *criteria for evaluating models* (Ministry of Education, 2014b). Furthermore, the existence of multiple models is addressed in the curriculum. The nature of models is mainly related to simplification and visualization and, to a lesser degree, adjustability to fit different purposes (Nielsen, 2018). The purpose, value and utilization of models are solely related to the context of education, and not to the way in which scientists use models in research. Furthermore, the curriculum provides a range of examples of different types of models. Finally, students' acknowledgement of models as a *facilitating mechanism for their own learning* is described in the curriculum (Ministry of Education, 2014b). In short, the curriculum describes two distinct elements of modelling as a competence: aspects of *meta-knowledge* and *aspects of modelling practices*.

In sum, and based on educational research and the curriculum, my proposed framework consists of three main elements: (a) *aspects of modelling practices*, (b) *meta-knowledge of models and modelling*, and (c) *subject-specific knowledge* represented in models (Figure 2.2).

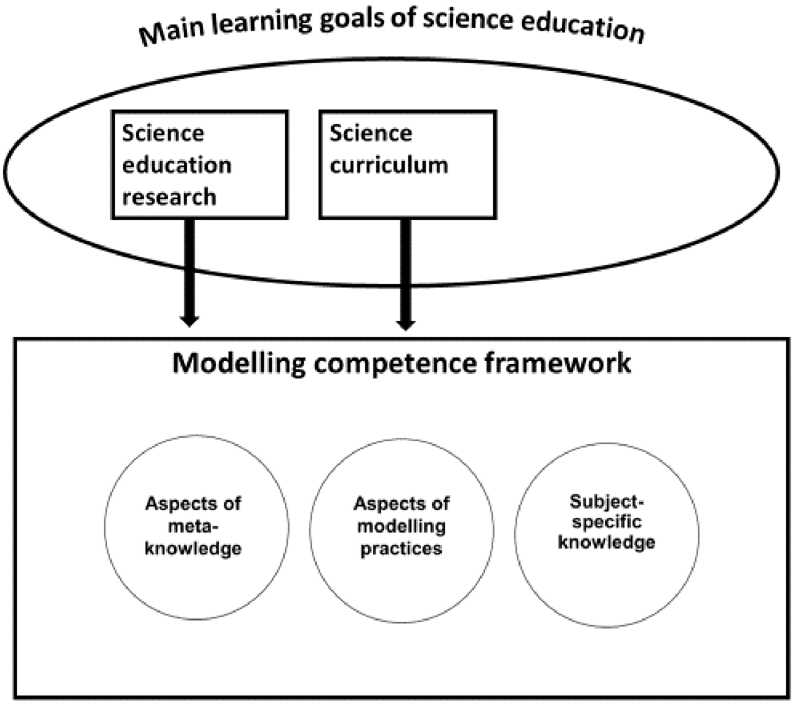

Figure 2.2 The construction of the modelling competence framework. The sources used to construct the framework are represented by the two boxes: science education research and science curriculum. The solid arrows indicate the sources used for the framework. The circle indicates how the main learning goals of science education framed the relevance of aspects from the different sources to be used to inform the framework.

2.3.1 The aspects of modelling practice in the framework

I will now provide further detail on how the educational research and the curriculum informed the element of *aspects of modelling practice* in my framework. This section will largely be based on educational research since the curriculum, as described above, only provides brief descriptions in this regard. Across the science education research literature, I have found (although termed differently in the individual sources) nine specific aspects of modelling practices considered essential for students to engage with during competence-oriented teaching and therefore relevant to include in my framework: (a) *describing*, (b) *explaining*, and (c) *predicting* (Grünkorn, Upmeier zu Belzen, & Krüger 2014; Nicolaou & Constantinou 2014; Schwarz et al. 2009; Van Driel & Verloop 1999), (d) *communicating* targeted at a specific audience (Lehrer & Schauble 2015; Oh & Oh 2011), (e) *designing* (Crawford & Cullin 2004; Papaevripidou, Nicolaou, & Constantinou 2014; Passmore, Stewart, & Cartier 2009; Schwarz et al. 2009), (f) *evaluating* and (g) *revising* (Grünkorn, Upmeier zu Belzen, & Krüger 2014; Miller & Kastens 2018; Papaevripidou, Nicolaou, & Constantinou 2014; Passmore, Stewart & Cartier 2009; Schwarz et al. 2009), (h) *comparing* (Gilbert 2004; Grünkorn, Upmeier zu Belzen, & Krüger 2014; Papaevripidou, Nicolaou, & Constantinou 2014; Schwarz et al. 2009), and (i) *selecting* (Campbell & Oh 2015). Aside from predicting and communicating, all the above practices are also found in the Danish curriculum (Ministry of Education 2014b). Aligned with Schwarz et al. (2009), this framework distinguishes between the different aspects of practices with models although the different practices typically overlap (e.g. evaluating is part of revising), are perceived as a prerequisite for each other (e.g. causal explanations as a prerequisite for predicting), and often enacted together in multiple ways. The nine aspects of modelling practices are illustrated in Figure 2.3.

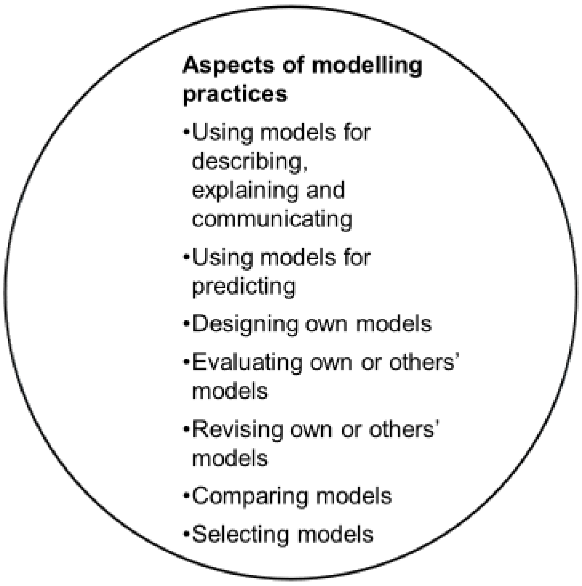

Figure 2.3 The nine specific aspects of modelling practices considered essential for students to engage with when teaching for modelling competence.

The first four aspects relate to the *functional roles* of models while the last five relate to the *application* of these functions. Following Krell & Krüger (2016), the functions of models can broadly be distinguished as either using models descriptively as a means of describing or explaining the referent or using models predictively as hypothetical entities and research tools. Based on Krell & Krüger's (2016) approach, I suggest clustering the *functional roles* of models into two distinct units in my framework: a descriptive use (describing, communicating and explaining) and a predictive use. In this way, I want to highlight that the predictive use of models is a salient aspect to include in a competence-oriented approach to models and modelling. Indeed, I would advocate for giving the predictive function of models a key position in a competence-oriented approach to models and modelling. For instance, the predictive function holds prospects for designing and using models to explore and raise new questions and hypotheses about a phenomenon, predicting 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 investigative or problem-solving purposes. In this way, my framework takes into account and articulates the fact that a competence-oriented approach to models and modelling comprises more than the descriptive approach predominant in current classroom teaching (Campbell et al., 2015; Oh & Oh, 2011).

The nine aspects and the distinction between the two functional roles of models are described in more detail in Table 2.1. Notice that, as shown in Table 2.1, my framework addresses both the descriptive and the predictive functions of models in all specifications related to students' engagement with designing, evaluating, revising, comparing and selecting models.

Aspects of modelling practices	Description
Descriptive use of models	Using models descriptively as a means of describing, explaining or communicating an idea or a phenomenon.
Predictive use of models	Using models predictively as tools for inquiry, problem-solving, sensemaking and/or as hypothetical entities representing different ideas of the referent.
Design own models targeted at a specific purpose	Students design models based on their own ideas, prior evidence and/or theories. The purpose could be related to a model's role in describing, communicating, explaining and/or predicting.
Evaluate own or others' models related to the usefulness decided by the purpose	Students evaluate models based on a model's power of representation, explanation and/or prediction related to a specific question, problem or purpose. Evaluation could be based on students' empirical testing and validation of models or how a model fits with other established models or types of knowledge.
Revise own or others' models to improve their affordance related to the usefulness decided by the purpose	Students revise own or others' models. The revision could change the communicative, representative, descriptive, explanatory, and/or predictive power of the model. Revision could be based on additional evidence, new findings, students' advanced sense-making or new theoretical aspects of the target.
Compare models related to the usefulness decided by the purpose	Students compare and evaluate multiple models representing the same referent to fit different purposes. The criteria for evaluation could be models' ability to represent, describe, communicate, explain and/or predict.
Select models for a specific purpose	Selecting an appropriate model to solve a specific task or problem based on ability and relevance related to a model's representative, descriptive, explanatory and/or predictive power.

Table 2.1. Descriptions of aspects of modelling practices that I included when constructing my modelling-competence framework.

2.3.2 Aspects of meta-knowledge in the framework

I will now expand upon how the educational research and the curriculum informed the element of *meta-knowledge* in my framework. A competence approach to modelling requires some kind of reflection related to the specific modelling practices in science and the rationale for students to engage in these practices, since students should be aware of what they are doing and why (Schwarz et al., 2009; Schwarz & White, 2005). This kind of reflection involves different aspects of what I call *meta-knowledge of models and modelling*. Looking across science education research literature, I found three main aspects of meta-knowledge (again, they were termed and structured differently in the individual sources) that ought to be included in a competence-oriented teaching: (a) the *nature of models*, (b) the *purpose, value, and utilization of models*; and (c) *models' merits and limitations.*

I will now go into further details for each of the three different aspects of meta-knowledge. It has been argued that knowledge of the first aspect, the *nature of models,* is at the heart of students' modelling competence and that future attempts to enhance learners' modelling competence should emphasize this specific aspect of meta-knowledge (Papaevripidou, Nicolaou, & Constantinou, 2014). In the Danish curriculum, *simplifications* and *visualizations* of something abstract or not directly observable take a prominent position in relation to the nature of models, while models' adjustability to fit different purposes attracts less attention (Ministry of Education, 2014b). Although I perceive simplification and visualization as salient characteristics of models to be included in science education, I advocate for adding and highlighting other characteristics in a competence-oriented teaching. More specifically, I think that addressing the nature of models in relation to their ability to *adjust* to fit different purposes *decided by the modeller, generalize* fundamental properties, and *generate* new ideas and knowledge (Schwartz & Lederman, 2005, 2008; Valk et al., 2007) would improve students' readiness and ability to apply scientific knowledge and practices in different situations. Highlighting the *tentative* (Valk et al., 2007) and generative nature of models would also enrich, and complement, students' engagement with designing, evaluating and revising their own models to account for new data, theoretical knowledge or their own advanced sensemaking (See Table 2.1 for more details).

In line with Krüger, Krell & Upmeier zu Belzen (2017), I acknowledge the potential for integrating *multiple models* into a competence-oriented teaching. Indeed, multiple models offer prospects for students to apply and reflect on how the selected features of different multiple models are useful for solving specific tasks during a wide range of problem-based situations. Taking multiple models into account in the framework would also tally with the (albeit rather vague) curriculum intentions on integrating multiple models into teaching (Nielsen, 2018). In line with Oh & Oh (2011), I also advocate that a qualified teaching on the nature of models must include knowledge about *what* can be modelled (e.g. objects, ideas, processes) and *how* these entities can be modelled (e.g. media, types). In sum, a competence-oriented approach to the nature of models should not only highlight models' ability to *simplify* and *visualize* but also include models' ability to *generalize*, *adjust* and *generate new knowledge*, as well as address the existence of *multiple models*, the *tentative nature* of models, the *what* and *how* to model, and put the *modellers' interpretations and intentions in a central position*. In addition, the nature of models must also include knowledge about *what* can be modelled and *how* these entities can be modelled by means of different types of models. The above characteristics related to the nature of models are summarized in Table 2.2.

Nature of models	Description
Specific characteristics related to the nature of models	A model is an interpretation of the referent and represents only partial, selected features related to a specific purpose decided by the designer of the model. Models are adjustable. For instance, the model could be reduced or increased in scope, scale and/or complexity to focus on a specific aspect or interest or to fit a specific purpose. A model is tentative and could be generative when revised to account for new data, theoretical knowledge or students' advanced sensemaking. Multiple models comprise different features or interpretations of the same referent decided by the purpose or due to insufficient knowledge. Models hold prospects for generalizing or highlighting some fundamental properties of the referent in a known situation transferable to new situations. Models could visualize something abstract or not directly observable, or simplify something complex.
Types of models*	Drawings and diagrams Models that primarily consist of symbols Physical models in 3D Animation models Analogies Interactive simulation models Kinaesthetic models
What does a model represent	Ideas, processes, events, phenomena, systems, or objects of the real world

*This categorization is inspired by Gilbert & Justi (2016).

Table 2.2 Knowledge to highlight on the nature of models in a competence-oriented teaching.

The second aspect of meta-knowledge relates to *the purpose, value, and utilization of models*. Across the research literature, I have found three different approaches related to this second aspect of meta-knowledge: (a) an *epistemic* (models in science research), (b) a *societal* and (c) an *educational.* First, the *epistemic* approach relates to how models are valued and utilized as epistemic and communicative artefacts in research to contribute to the production, testing, dissemination, and acceptance of scientific knowledge (Gilbert, 2004; Lehrer & Schauble 2015). Along the same lines, it has been argued that the major steps in the process of scientific modelling in particular should play an important role in science teaching when working with meta-knowledge related to the purpose and utilization of models in science research (e.g. Nicolaou & Constantinou 2014; Schwarz and White 2005). Second, the *societal* approach relates to the relevance of integrating the purpose, value, and utilization of models in *society* into teaching (Miller & Kastens, 2018; Valk, van Driel & Vos 2007; Windschitl & Thompson, 2006) for instance, how models are used for predicting climate change or how they are used for predicting how a change in fisheries practice affects a fish population. Third, the *educational* approach has to do with meta-knowledge related to models as a means for students' sensemaking (Schwarz et al. 2009) and as teaching tools (Papaevripidou, Nicolaou, & Constantinou 2014).

The third aspect of meta-knowledge I found in the science education research literature and in the curriculum *relates to models' merits and limitations* (Gilbert 2004; Schwarz & White 2005; Valk, van Driel, & Vos 2007), including criteria for evaluating models (Ministry of Education 2014b; Schwarz et al. 2009; Schwarz & White 2005). I consider this kind of meta-knowledge important to include in a competence-oriented teaching. For instance, students must have knowledge of the limitations and merits of models in terms of the usefulness decided by the purpose if they are to be able to evaluate, design and interpret models. As an example, students must recognize if and how relevant components, relations, and causes and functions of the target are represented in the model, how the degree of precision could justify the power of explanation or prediction, and model limitations by ignoring or holding some variables constant (Schwartz & Lederman, 2005; Valk et al., 2007). The three different aspects of meta-knowledge considered essential for students to engage with during a competence-oriented teaching are summarized in Figure 2.4.

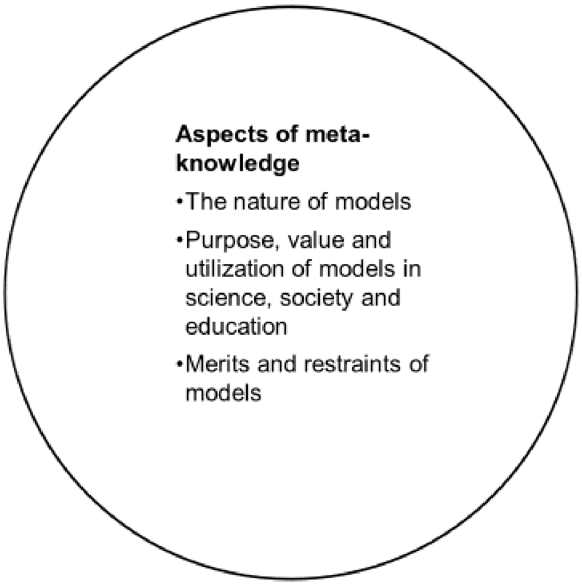

Figure 2.4 The three different aspects of meta-knowledge considered essential for students to engage with when teaching for modelling competence.

2.3.3 The subject-specific knowledge in the framework

In this section, I will argue for the inclusion of a third element in the framework which I call *subject-specific knowledge.* Since modelling in science entails models representing something from the natural world, teaching with and about modelling should also comprise a science content knowledge element (Lehrer & Schauble, 2015). The integration of a subject-specific knowledge element is also in line with education documents that state that students' engagement in modelling is not really an epistemic practice of science in the absence of reasoning with and about disciplinary core ideas in order to make sense of the world or solve a specific task (NRC, 2012). In addition, subject-specific knowledge still holds a dominant position in the external assessment system and in the Danish curriculum (Nielsen, 2018), as well as in teachers' existing practice and the way they perceive school science (Campbell et al., 2015; Schwarz et al., 2009). In this way, the addition of a subject-specific knowledge element offers the potential of making the framework more manageable and meaningful for teachers, in contrast to a framework that solely approaches modelling as a practice detached from the subject-specific knowledge represented in the model. I therefore advocate for adding this third *subject-specific knowledge* element into the framework. This subject-specific knowledge could be an idea, an object, a phenomenon, an event, a process, or a system of the 'real' world represented in a model (Gilbert & Justi, 2016; Oh & Oh, 2011). As a counterweight to teachers' predominant approach to models as only representing known objects or phenomena (Crawford & Cullin, 2004), I place *idea* at the front (Figure 2.5). In this way, I wish the framework to emphasize models' characteristics as hypothetical entities used to "grapple with" and develop new ideas of how the world works.

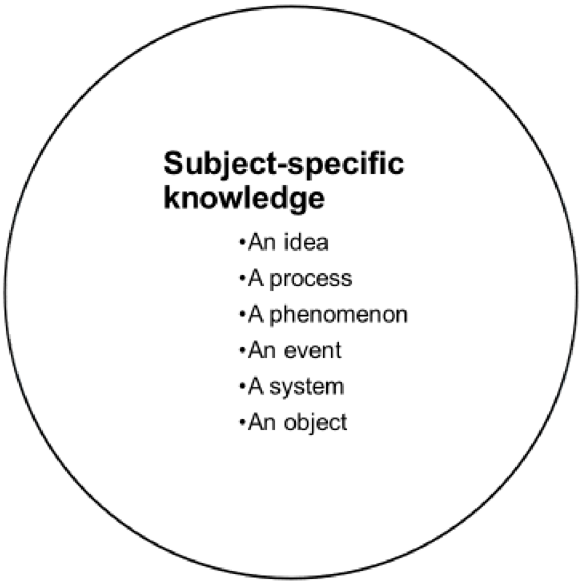

Figure 2.5 The subject-specific knowledge represented in the model is part of a teaching for modelling competence.

2.3.4 A modelling competence framework

Based on the reasons given above, I suggest that the main elements to be integrated into a competence-oriented approach to models and modelling are: (a) the *subject-specific knowledge* represented in the model, (b) *meta-knowledge of models and modelling*, and (c) *aspects of modelling practices*. Indeed, a competence-oriented teaching must offer students more than a knowledge of the distinct elements of subject-specific knowledge, meta-knowledge, and (rote) performance of scientific modelling practices (Berland et al., 2016; Lehrer & Schauble, 2015). Applying the concepts of competence (cf. Busch, Elf & Horst, 2004) and action (Nielsen & Gottschau, 2005) to students' engagement with models and modelling implies a *motivated,* *reflective,* and *applied use* of different kinds of knowledge and practices purposefully directed at *solving a subject-specific problem or task* in *different situations*. If modelling competence is to be enacted in this way, it requires teaching that facilitates students' intertwining of meta-knowledge, subject-specific knowledge and aspects of modelling practices. This point is illustrated in Figure 2.6.

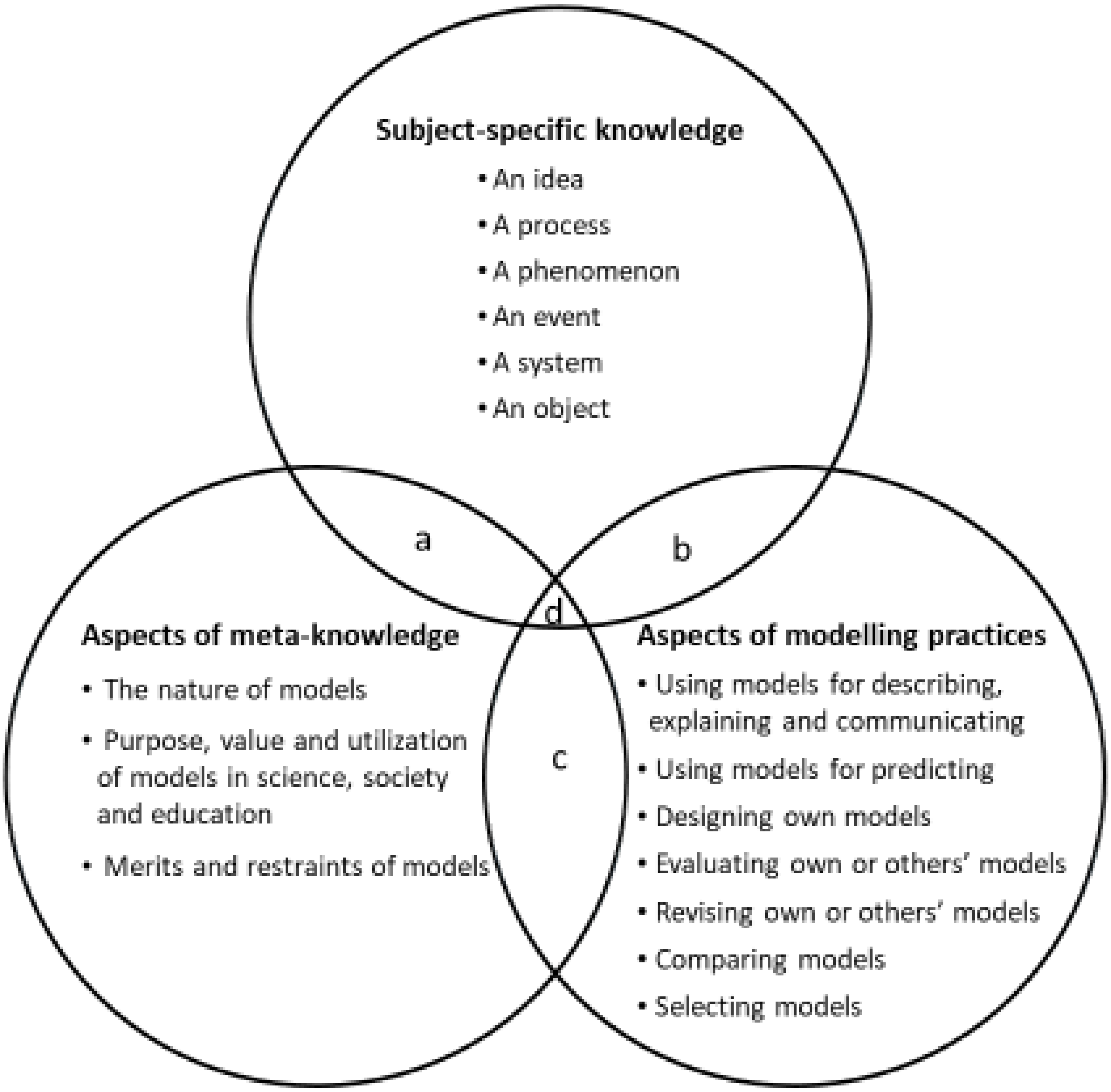

Figure 2.6 The modelling competence framework. This framework consists of three main elements: *subject-specific knowledge* represented *in models, meta-knowledge* of *models and modelling,* and *modelling practices*. The areas with overlapping circles illustrate how the different elements could be enacted together. The different combinations of intervention between the three main elements are illustrated by overlapping circles each denoted by a letter (a, b, c, d).

For instance, by asking students to design a carbon cycle for prediction purposes they need to *apply* subject-specific content knowledge in order to select and relate the relevant components and to identify relevant variables, and meta-knowledge to evaluate limitations to their model. At the same time, students' engagement with modelling practices offers the prospect of facilitating their *development* of meta- and content-knowledge, for example, by providing students with the opportunity to experience how a model is not actually a representation that accurately depicts every aspect of its target but only captures certain features or components related to the design purpose. The design of the model likewise offers the prospect of a more advanced understanding of subject-specific knowledge with regard to the relationships between the different elements in the cycle-model. The above example would correspond to the area of the three overlapping circles denoted d) in Figure 2.6, since aspects from all three elements of the framework were applied and developed during the task.

It might not always be appropriate and relevant to combine all three elements simultaneously in the teaching, however. Dependent upon the specific purpose of engaging the students with models and modelling, the emphasis, combination, and degree of overlap between the two or three elements may therefore differ. In fact, as a preparatory component to a more competence-oriented approach, it could even be relevant to treat each element separately before intertwining two or more elements in a teaching situation. As mentioned in the figure caption, the different combinations of intervention between the three main elements are illustrated by overlapping circles denoted by the letters a, b, c and d in Figure 2.6.

I argue that by including the three key elements *(a) subject-specific knowledge*; *(b) meta-knowledge;* and *(c) modelling practices*, and intertwining them in the construction of my framework, the framework would not only be aligned with a competence-oriented approach to models and modelling as suggested by educational research but also be in line with three of Hodson's (2014) four learning goals for science education: (a) *learning science* - acquiring and developing the major achievements of science e.g. the concept, the models, and the theories; (b) *learning about science* - developing an understanding of the nature of science and methods of science e.g. characteristics of scientific inquiry, the role and status of the knowledge it generates, the ways in which the scientific community establishes and monitors their practice, and awareness of the complex interactions between science and society; and (c) *doing science* - engaging in and developing expertise in scientific inquiry and problem-solving.

The alignment between my framework and the main learning goals of science education is specifically demonstrated when comparing the frameworks' elements and their components with Baek & Schwarz's (2015) more detailed arguments for how models and modelling can facilitate students' learning. Their arguments are that models and modelling can facilitate students' learning through: (a) advancing content knowledge by *making invisible processes, mechanisms, and components visible*; (b) increasing their understanding of the way that science functions through *sharing, evaluating, and revising models*; and (c) encouraging students to develop their epistemological thinking by allowing them to consider the roles of empirical evidence *when constructing and revising models*. This fits well with my framework. Addressing models and modelling as illustrated in my framework in Figure 2.6 would therefore not only be aligned with a competence-oriented approach to models and modelling as suggested by educational research but would also offer the prospect of facilitating students' learning with regard to the three main goals of science education. An overview of the framework, and the sources (curricular and educational research) and the framing (learning goals) of its construct, is provided in Figure 2.7.

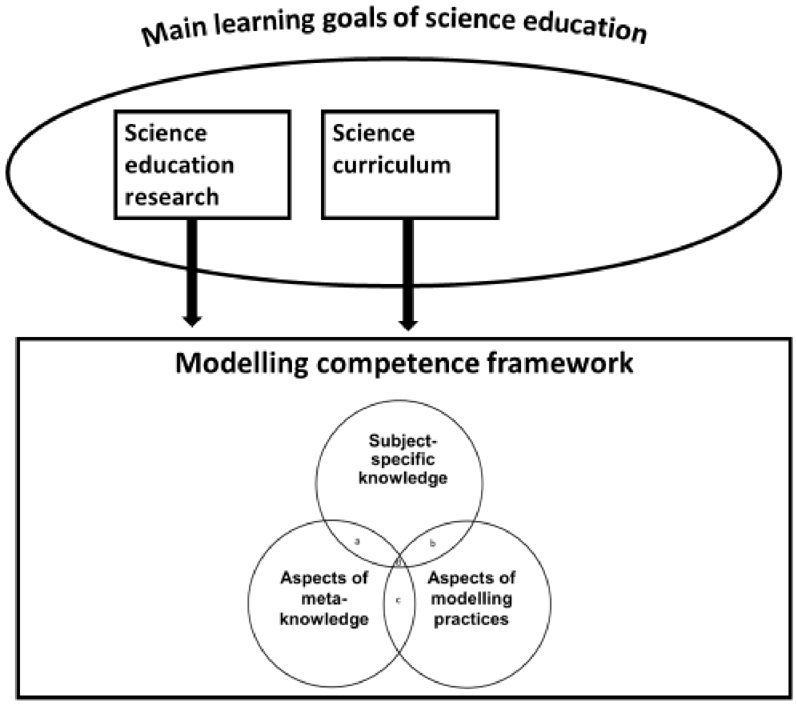

Figure 2.7 An overview of the framework, and how the educational research and curriculum framed by the overall learning goals of science education informed the construct of the modelling competence framework.

3. Motivation, Research Design and Methods

In this section, I first describe my motivation for this project and how it informed my approach to knowledge generation and research design. Then, I outline the research design and its different phases, how the participants in the project were identified, and the role and purpose of the two individual sub-studies. Finally, I present the methods used for data sampling and analysis.

3.1 The purpose of, and approach taken to, knowledge generation

My motivation for engaging in this Ph.D. project was a fundamental intent to contribute knowledge useful to solving challenges in school science with regard to teachers' possibilities for adopting curriculum intentions in their teaching. Moreover, I wished to understand, document and disseminate the knowledge that streams from the teachers' perspectives in this regard, based on the experiences they draw from their own teaching practice. Along the same lines, I found it valuable to learn from the teachers' suggestions of how to deal with the challenges they had encountered. Finally - and perhaps due to my background as a teacher educator - it made very good sense for me to design the research so that the study not only explores teachers' practice but simultaneously contributes to developing it. My motivation for this project was thus to contribute knowledge that can help narrow the gap between curriculum intentions and teachers' practice (Van Driel, Beijaard & Verloop, 2001).By considering how the knowledge from this project could contribute to solving specific challenges or problems, the aim of this thesis goes beyond a basic research approach mainly aimed at *describing, explaining and understanding* a specific phenomenon (or problem). While the aims of this thesis do overlap with the aims of basic research, it also shares similarities with applied research because it aims to contribute knowledge that could help understand the nature of a specific problem in order to *use the knowledge generated to intervene in the specific problem* (Patton, 2002). Moreover, I did not want to simply suggest solutions solely based on my own investigation of teachers' existing practice and theoretical considerations. I wanted to cooperate with the participating teachers to *explore and develop their own practice* in a *context-specific situation*. By taking into account teachers' active participation in exploring and developing their own classroom practice as part of the generation of knowledge, my study resembles important aspects of action research (Gustavsen, 2003; MacDonald, 2012; Nielsen & Nielsen, 2015). Moreover, my aim was to generate a picture of how Danish science teachers enact curriculum intentions – a picture that is more nuanced than has been reported elsewhere (e.g. EVA, 2012) and which includes teachers' reasons for their enactment decisions. Since this approach is time-consuming, it limited the number of teachers and schools that could be involved. In this regard, I also found it relevant to explore whether findings from a school- and teacher-specific context resembled findings from a broader range of school contexts and teachers. The above approach to knowledge generation and the purpose of this knowledge production guided my overall research design, including my data sampling strategy and analytical approach.

3.2 Outline of the different phases of the research design

Before entering into the details of the research design, I will give a short description of the two sub-studies that comprise the project. The first sub-study was a small-scale school-based qualitative study of three teacher pairs' reflections and planning related to their teaching with and about models and modelling to facilitate students' modelling competence (the school-based sub-study). The second sub-study was a large questionnaire-based quantitative study (the questionnaire sub-study). The questionnaire study focused on teachers' use of models and modelling and their reasons for this use, related to their possibilities for adopting the curriculum intentions for teaching students' modelling competence.I will now give an outline of the research design of the project. This was divided into six phases with different activities and purposes, see Figure 3.1.

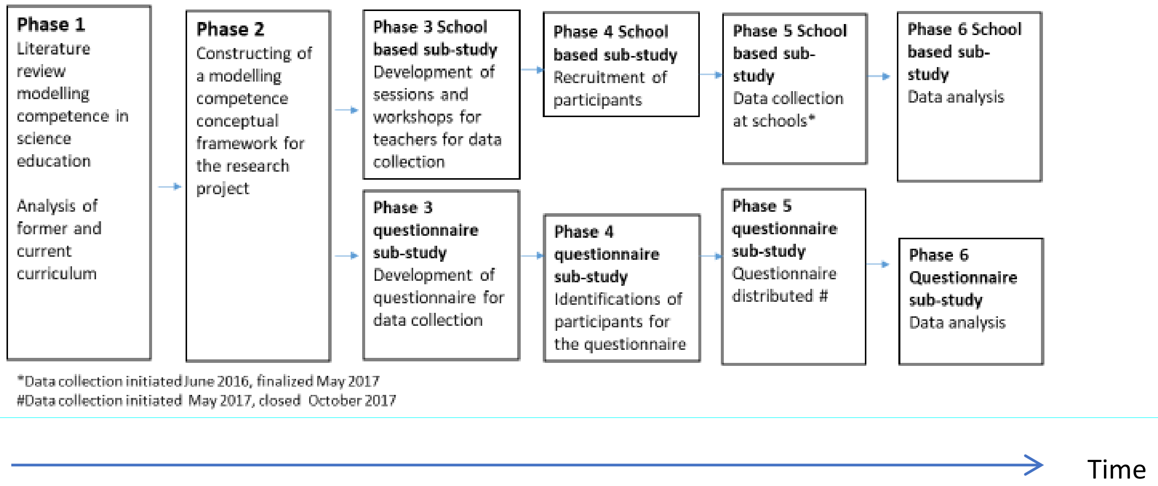

Figure 3.1 Outline of the six phases of the research design. Phases three to six are divided into two separate sub-phases as the sub-studies were not initiated and completed simultaneously.

The first phase consisted of an analysis of the current curriculum (Nielsen, 2015; Paper 1) focusing on its merits and limitations for supporting teachers to adopt modelling as a competence in their teaching. A comparison was also made between the pre-2014 curriculum and the current curriculum, with a focus on how models and modelling were directly or indirectly addressed (Nielsen, 2018; Paper 2). Moreover, I search the literature in this phase to explore how other scholars in science education have addressed modelling as a competence in school settings in primary or lower secondary school. Based on the literature search and analysis of the current curriculum from phase one, a modelling competence-oriented framework (Figure 2.6) was constructed (Nielsen & Nielsen in review; Paper 3). This framework represents my theoretical stance on modelling competence. Below I will describe in detail how this framework guided my data collection and analysis. In phase three, I developed each of the two sub-studies in my research project: the small-scale school-based qualitative study and the large questionnaire study mainly based on quantitative data. While the main purpose of the school-based study was to provide a rich in-depth description, the main purpose of the questionnaire study was to provide a broad, systematic description in order to answer the research questions. In phase four, participants were identified and recruited for each sub-study. Data were collected from the school-based study, and the questionnaire was distributed in phase five, with the data analyzed in phase six. In the next section I will elaborate on how the two different sub-studies fulfilled different purposes in my efforts to answer the research questions.

3.3 The role and purpose of the school-based and the questionnaire sub-studies

As mentioned above, the school-based and questionnaire sub-studies served different purposes in terms of answering the overriding research questions. The purpose of the school-based sub-study was to gain an in-depth description and understanding of a small number of teachers’ (a) current and forthcoming practices with models and modelling; (b) the reasons for their choices in this regard; and (c) how they operationalize different aspects of the curricular modelling competence goal into specific learning goals and modelling activities. In contrast, the purpose of the questionnaire sub-study was to gain an overview of Danish science teachers in lower secondary school in terms of (a) the teachers' background related to teaching science; (b) how teachers perceive their own practice of models and modelling as well as their reasons for their choices in this regard; and (c) how the teachers perceived the possibilities for adopting the modelling aspects of the current curriculum in their teaching practices. The main role of the school-based sub-study was therefore to provide a rich, in-depth and context-specific understanding of how teachers reflect on, interpret and operationalize the curricular competence-oriented approach to models and modelling in their existing and future teaching practice. In contrast, the main role of the questionnaire study was to cover many different school contexts and teachers and thus provide a more overall, broader and more systematic picture of Danish science teachers' self- perceived practices with models and modelling, their reasons for this practice, and conditions for enacting the curriculum intentions - as well as the range among the teachers in this regard. The different roles and purposes of the school-based and questionnaire sub-studies guided how I designed my data sampling strategy. I will elaborate on this aspect in 3.4 for the school-based sub-study and 3.5 for the questionnaire sub-study.

3.4 The data sampling set-up and methods in the school-based sub-study

This section describes the recruitment of participants for the school-based sub-study. The sampling strategy, methods and different kinds of data generated for this sub-study will then be described. Finally, I will also briefly describe how I have adjusted my sampling over time in response to the feedback from the teachers and the experiences gained.

Recruitment of participants for the school-based part of the project

The lower secondary science teachers who participated in the school-based study for my project were all volunteers, chosen on a 'convenient' basis (Onwuegbuzie & Collins, 2007). One of the first challenges I encountered during the project was to find science teachers who had the time and willingness to participate. It should be recalled that this project was initiated in the same teaching year as a new school reform, a new curriculum and new working conditions were introduced in Danish primary and lower secondary schools (increasing teaching load and offering less time for preparation).Teachers were therefore generally hard pressed for time and had, among other things, a large number of new requirements that they needed to implement in their teaching. Using my existing network from other projects, practice schools, and former students from teacher training and in-service education, I was nevertheless able to find 14 biology teachers. However, seven of these withdrew shortly after the initial meetings (new work, no schedule for science teaching, lack of time) while a teacher-team of three, supposed to be my pilot team, withdrew after six months (illness, new positions at another school). After some effort, I was able to find a new teacher pair: one teaching biology and the other teaching physics. During the allocation process and the initial meetings with the teachers, I also realized that, to put the puzzle together (establish a team-pair of colleagues at the same school) and to make it meaningful for the participating teachers (a new trans-disciplinary exam and units, the position, number and distribution of different science subjects in their teaching schedule), I needed to expand my project from working only with biology to also include aspects of physics/chemistry and geography.

The result of this process was that this sub-study involved six teachers who were employed at three schools located in urban and suburban areas of the Capital Region of Denmark. Two of the teachers were my former students (D1, F3), two of the other teachers I knew from a former research project (A2, B2), and the last two teachers were colleagues of the other participants (C1, E3). E3 withdraw after the third planning session/workshop. The participating teachers had very different teaching experiences (from two to over 20 years). The teachers also taught different numbers of science subjects in lower secondary school (1-3 subjects). All teachers taught physics/chemistry, all except one (E3) taught biology, and three taught geography as well (A2, B2, C1). All the teachers had a teaching degree from teacher training involving courses in general education as well as science education. Two of the teachers (A2 & C1) also had a master's degree in science (in Denmark, primary and lower secondary school teachers normally have a bachelor's degree). Three of the teachers (A2, B2 and E3) had participated in a specific in-service course dealing with models. If nothing else is stated, I define an "experienced teacher" in the school-based study as a person with >20 years of experience teaching science and who participated in the above-mentioned course (i.e. A2 and B2).

Sampling strategy, methods and data

To collect data, I designed a set-up comprising a number of activities in each school. All the activities were carried out in the teachers' classroom or working space in order to be on the teachers' own ground and to minimize teachers' workload in participating in the project. Likewise, the easy access to teaching materials and student-generated products facilitated my efforts to direct the talk-in-interaction towards the teachers' concrete classroom experiences. Moreover, my visits to the school added to my understanding of their working conditions (classroom, laboratory and IT facilities; frequency of interruptions during our meetings; their students' abilities etc.). As mentioned above, I managed to engage six teachers employed at three schools in this part of the project. All the activities involved teachers talking about their existing and forthcoming teaching. I used a "teacher in pair set-up" comprising teachers employed at the same school. In doing so, I aimed to facilitate a reflective and generative dialogue fostered by the teachers' different experiences and perspectives (cf. Bryman, 2012) in order to generate richer and deeper knowledge than could be generated by an individual discussion between myself and a single teacher. Moreover, and similar to a qualitative focus-interview, the pair set-up is suited to exploring and giving importance to teachers' shared views and understandings (Kvale, 2006).

I will now describe the different activities in detail. Figure 3.2 provides an overview of the activities. All activities were conducted at all three schools.

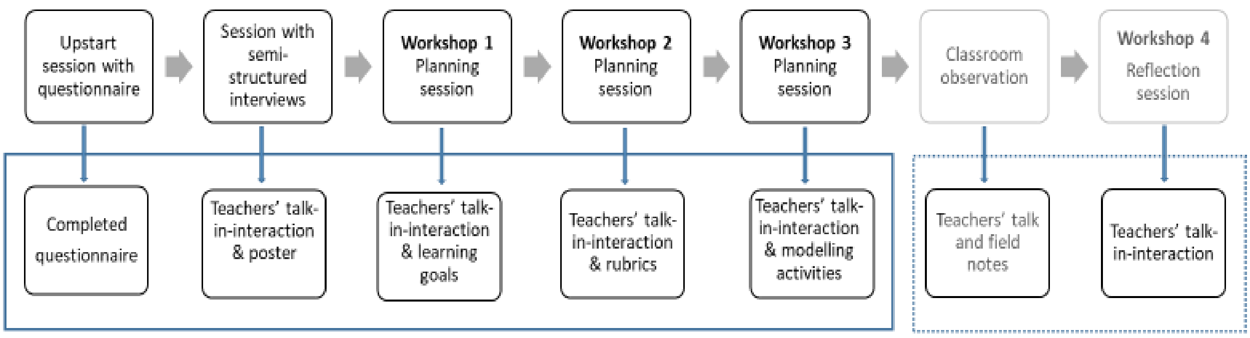

Figure 3.2 The activities in the school-based sub-study and the data generated through those activities. The data within the solid frame are primary data and the data within the dotted frame are supplementary data.

The first activity was a short start-up session. The aim of this session was to outline the components and intentions of the study, clarify and adjust reciprocal expectations, and resolve practical planning issues. The teachers were asked to fill in and provide feedback on the questionnaire used in the questionnaire study. Aside from providing me with feedback on improving the questionnaire, I also used the teachers' responses as background for the next activity with the teachers.

The second activity was an explorative semi-structured interview (Kvale, 2006) framed as a reflective session focusing on the teachers' current teaching with and about models and modelling – but also put into a forward perspective for their future teaching. As further described in section 3.3, I wanted a broad description of teachers' experiences and meanings from their own perspective. I therefore chose to undertake an explorative and qualitative interview focusing on teachers' own concrete teaching experiences and their reflections in this regard. I structured the interview session around a range of labels with pre-formulated statements. The labels were placed on a table and these were regularly picked up by the teacher or myself during the session. In this way, the statements also facilitated the talk-in-interaction and teachers' reflections during the session.

The statements were framed by the modelling competence-oriented framework (Figure 2.6), the aspects related to models and modelling in the current curriculum, and science education research suggestions on the learning prospects for engaging students in models and modelling. In so doing, I aimed to explore the alignment between theoretical educational intentions and justifications for integrating models and modelling into science education, on the one hand, and teachers' practice and rationales in this regard, on the other (Figure 1.1).

A range of statements was related to different aspects of modelling practices. For example, "*Students use models for predicting how a certain phenomenon may develop (e.g. during time or in a different context)*" or "*Students evaluate the limitations and scope of certain models in relation to purpose*" and "*Students create models based on their own inquiries*" (further examples in Appendix 1). The teachers were asked to elaborate on how the statements reflected the use and function of models and modelling in their current teaching. In addition, the teachers were asked to design a poster that was placed on the table during the session and intended to illustrate their ranking of some of the statements with regard to frequency of use in their current teaching. During the session, both teachers and I added comments or additional statements to the poster. Inspired by timeline interviews (Adriansen, 2012), the intention was to invite ownership of the process and enable an atmosphere of trust by using the poster as an artefact that would make the session a collaborative process based on the teachers' experiences and, at the same time, make the data generation visible to all. In this way, I used the interview sessions as an attempt to explore the significance of the teachers' own experiences. The poster also acted as a 'collective memory', easy to return to for verification of my interpretations of the teachers' utterances or for clarification purposes during the session. An example of a poster from a workshop session (C1, D1) is given in Figure 3.3. I furthermore encouraged the teachers to reflect on the prospects of adjusting their existing practice and, if so, why and how.

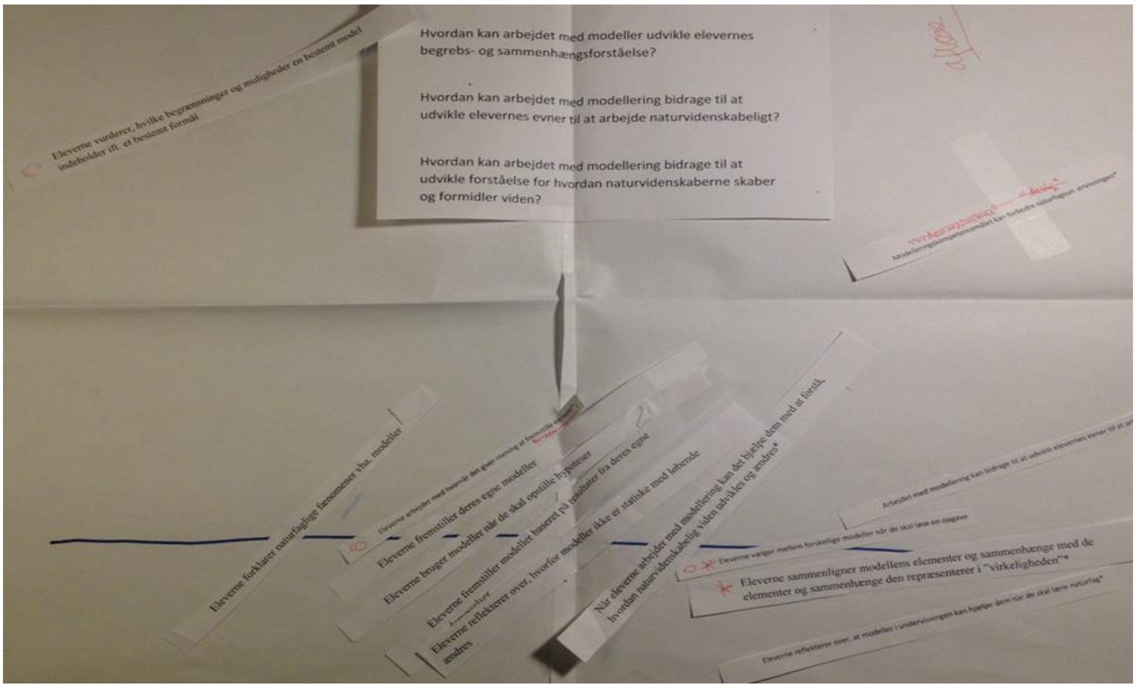

Figure 3.3. An example of a teacher pair's ranking of the pre-formulated statements reflecting different modelling practices with regard to their frequency of use in the teachers' current teaching.

While the statements noted above related to different modelling activities, other statements reflected a more general approach to teachers' rationale for integrating models and modelling into their teaching, for instance, "*Use of models offers the prospect of improving science education*". Moreover, some statements directly mirrored how models and modelling could contribute to accomplishing the specific purposes of science education. The formulation of these statements was guided by three of Hodsons' (2014) four suggested learning goals for science education. For example, learning science: "*Students use models to explain a certain phenomenon*", about science: "*Students reflect on when it makes sense to create a model*", and doing science: "*Models can facilitate students' abilities to work scientifically*". In addition, I used excerpts from the overall purposes of lower secondary science education in Denmark. As with the pre-formulated statements, these extracts were also used as a mediating artefact during the interview sessions. The sessions ran from 145 to 200 minutes.

The third activity was three planning workshops related to the teachers' future teaching. One workshop focused on teachers' reflections and formulation of learning goals for the students, another on teachers' design of rubrics with differentiated assessment criteria, and the final one on teachers' development of modelling activities. The main purpose of the workshops was to describe and understand how the teachers interpret and operationalize the curriculum intentions into concrete learning goals and modelling practices. The workshops also served as a means to obtain data with regard to what teachers perceived as a manageable and meaningful way of handling models and modelling in their teaching.

Although the teachers talk-in-interaction played a dominant role in the workshops, I also took an active part in the planning. For instance, I not only listened but also raised different kinds of questions inspired by Kvale & Brinkmann's (2015) nine types of questions in qualitative studies. Moreover, I acted as a "communication interface" of ideas between the three schools. Likewise, I contributed ideas when asked directly by the participating teachers. Finally, I brought workshop materials with me to be used for further reflection and inspiration. For instance, an initial version of the modelling competence framework was presented and discussed with the participants. Pre-described labels reflecting different principles for rubric design were also used to elicit a discussion about the teachers' own design of rubrics. As with the pre-described labels for different aspects of modelling practices used in the semi-structured interviews, the materials I brought to the workshops acted as mediating artefacts for an open and collaborative process. Figure 3.4 illustrates an example of a teacher pair's (A2, B2) work-in-progress prioritizing what kind of principles should be used in the design of their rubrics.

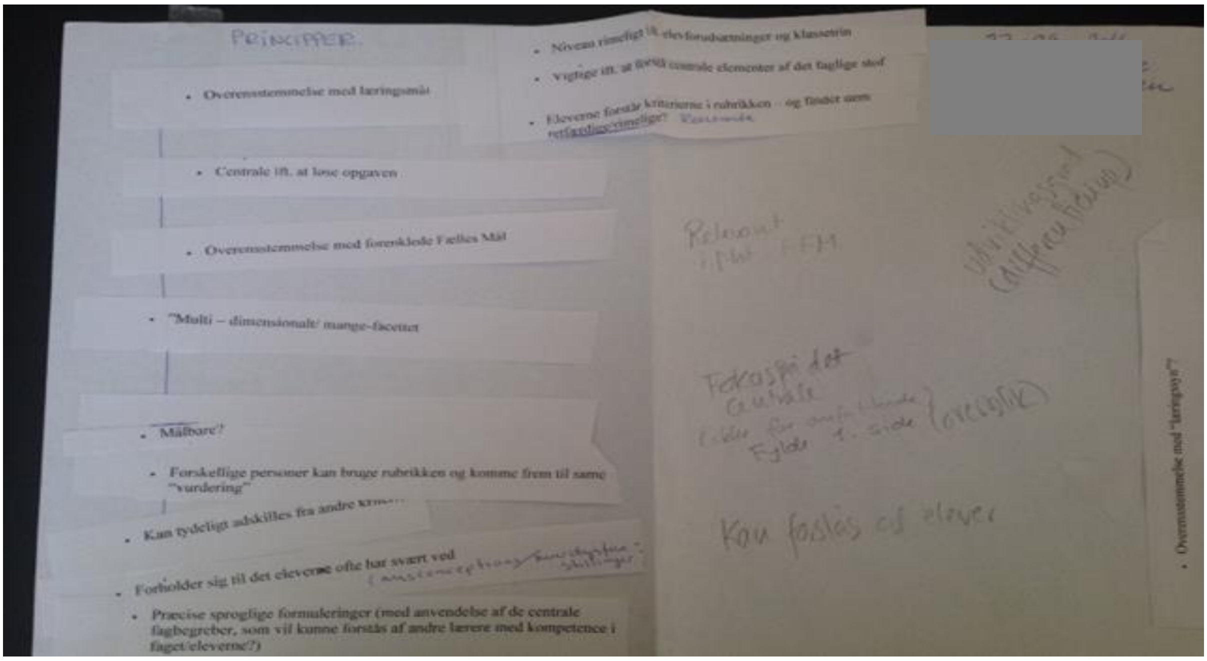

Figure 3.4. Example of how pre-designed labels were used as a mediating artefact in a teacher pair's work-in-progress prioritizing what kind of principles should be used in the design of their rubrics. The notes are the teachers' supplementary principles and remarks.

Please note that although, for dissemination reasons, the diagram in Figure 2.2 reflects a highly uniform set-up, the actual enactment of the activities painted a more varied picture. For instance, some teacher pairs had more possibilities for supplementary workshops. Likewise, specific teachers' heavy workload on occasions, or teachers withdrawing from the project, meant that some of the activities were conducted in a more limited way (by only one teacher, see Appendix 2). Moreover, some teachers (A2, B2) preferred to change the order of workshops 1, 2 and 3. Along the same lines, workshops 1, 2 and 3 were more or less merged (e.g. adjusting the learning goals to fit modelling activities or vice versa) by the teachers. I audio-recorded both the teachers' talk-in-interactions during the start-up session, the semi-structured interviews and the three workshops. It is worth noting that the teachers' talk-in-interaction from the interview part of the school-based sub-study provided a wealth of information related to the research questions. In contrast, the information in the talk-in-interaction from the workshop sessions had a more "sporadically spread in spot richness of information" related to the research questions.

Adjustment of sampling strategy and the data set

I will now briefly describe how I adjusted my empirical part of the research design over time in response to the experience I gained and how this rethinking influenced the status of the different sources for my data set in my research project. In my original research design, my intention was to explore how the teaching activities emanating from the planning sessions were enacted in the classroom. Likewise, I wanted to describe in detail how the teachers attended and responded to the learning intentions described in the planning sessions' rubrics and learning goals in their classroom practice[5]. To fulfill the above intentions, I expected to use classroom observations supplemented by audio recording of teachers' dialogues with the students. However, in the process of the study, I realized that I needed to scale down my intentions of what was possible within the timeframe. One reason for the need to scale down related to challenges encountered with the participants withdrawing from the project and practical issues in setting up meetings with the teachers. Another reason was my underestimation of the time needed for proper analysis of the qualitative data. In retrospect, I should have started analyzing the data earlier in the process. This would not only have provided me with valuable information for the next step in my data collection but would also have enabled adjustment of the research design at an earlier stage. In this light, I distinguished between primary and supplementary data sets. The data generated from the semi-structured interviews and workshops 1, 2 and 3, and the materials emanating from the workshops, were used as the primary data sets while the data from the enacting of these materials were considered supplementary data. While the supplementary data does not form part of my main data analysis, they still play an important role in understanding teachers' modelling activities and as useful background information for interpreting and understanding the primary data set. My observations (12 observations over a 8 month period) of how the enacting of the modelling activities developed during the workshops sessions were particularly valuable in this regard.

As shown in Figure 3.2, I also held a fourth workshop. This workshop was framed as a reflective session. At this workshop, the teachers' reflected on their own practice with a view to their future teaching and perceptions of meaningfulness and manageability for enacting the curricular intentions in their day-to-day teaching. In addition, I wanted the teachers to be involved in the analysis of the data (Greenwood & Levin, 2007). To fulfill the above intentions, I integrated reflective sessions into my data sampling set-up, composed of teacher pairs reflecting and commenting on their own practice based on written and audio extracts from their own teaching. I facilitated three reflective sessions. However, I found that the teachers were not interested in this part of the project (already planning new subjects for their teaching) and the few sessions I organized were not successful either with regard to teacher feelings of "comfort" during the sessions or with regard to the depth of the data generated. I realized that this combination of teacher-development and data collection requires long-term effort, experience from me as a facilitator as well as experience and commitment from the participants which would not be possible to obtain within the timeframe of this project. I therefore decided to remove this part of the data sampling from the project. While the data are not included in the data set, the experience I obtained still played a role in my understanding of the primary and supplementary data set. Table 3.1 provides an overview of the data set from the school-based sub-study and the information I intended to obtain from them.

[5] The observation played an important role in my initial project description, which had a strong focus on teachers' intended and enacted use of formative assessment. This part of the project was only included in the first part of my empirical data sampling together with the pilot teacher team that withdrew from the project. Realizing the need to focus my project, and not being able to continue my work with this team of teachers, this part of the initial project is not included in this thesis. This part of the study is described in more detail in: (a) Dolin, Bruun, Nielsen, Jensen & Nieminen (2018), and (b) Nielsen, Dolin, Bruun, & Jensen (2018).

Data set	**Information I intended to obtain from the different data sources**
Completed questionnaires (n = 6)	An overview of teachers' self-perceived practices with models and modelling, their reasons for this practice, and conditions for enacting the curricular modelling competence intentions. Used as background for planning the semi-structured interviews.
Audio recordings of teacher pairs' talk-in-interaction during semi-structured interviews (n_{pairs} = 3; h = 8,5)	A rich, in-depth and context-specific description of specific teachers' (a) *current and envisaged* practices with models and modelling, and (b) the reasons for their choices in this regard.
Audio recordings of teacher pairs talk-in-interaction during three planning workshop sessions ($n_{ses.}$= 9; h = 36)	A rich, in-depth and context-specific description of specific teachers' (a) *planned* practices with models and modelling, and (b) the reasons for their choices in this regard.
Modelling activities developed during the planning workshop (n_{act}. = 20)*	Examples of how specific teachers interpret and operationalize different aspects of the curricular modelling competence goal into modelling activities – in a way they perceive as manageable and meaningful.
Learning goals[#] (n_{goals}= *27*) and rubrics developed during the planning workshops ($n_{rubrics}$= 5)**	Examples of what specific teachers perceive as being the learning prospects of their developed teaching modelling activities for facilitating students' modelling competence and how.
Field notes from classroom observations and audio recordings of teachers' dialogues with students during the enacted modelling activities (n_{obs} = 13; h = 30)	Examples of how the planned teaching activities are enacted in the classroom. Examples of what and how teachers addressed and responded to the learning goals and assessment criteria during their teaching. Please note that this data is only supplementary data in the research project.

*For some of the activities it was difficult to define *the* modelling activity, since some activities contained many sub-activities and other activities involved students engaged in different aspects of the same activity.

[#] Some teachers formulated learning goals for their entire teaching session while other teachers formulated very specific goals for specific modelling activities or only formulated a progression of learning goals in their rubrics. In this light, I do not think there is any meaning in counting the exact number of learning goals. I have instead provided a range of exemplary goals in Appendix 3.

**An example is provided in Appendix 4.

Table 3.1. Data sets from the school-based sub-study and the information I intended to obtain from them. h = hours of audio recordings.

3.5 The participants and the design of the questionnaire sub-study

This section describes how the participants for the questionnaire sub-study were identified. I go on to explain the reasons behind the choice of using a questionnaire for data sampling, the development, design and distribution of the questionnaire.

Identification of participants for questionnaire sub-study

No records exist of how many, who, where or in what subject school teachers are teaching science in Denmark. The only record available was an email list from the Ministry of Education comprising all Danish schools with a science exam in grade 9, which shows that these schools teach science from grades 7 to 9. Based on this list, it was possible to get in touch with all lower secondary schools in Denmark that teach science from grades 7 to 9 (n = 1,796). The local school administration at the schools was contacted (June 2016, and follow up mail November 2017) in order to obtain the science teachers' work email addresses. A total of 206 schools responded (11.5% response rate; n = 1,796) providing a total of 718 science teachers' email addresses (including 115 non-functioning emails). The electronic survey questionnaire was then distributed directly via the functioning emails to 603 lower secondary science teachers (May, 2017). With one survey reminder after 7 weeks, 246 teachers employed at 153 different schools responded (40.8% response rate; n = 603) As shown above, the school-based and questionnaire sub-studies differed with regard to the number of participants.

As previously mentioned, the purpose of the questionnaire sub-study was to obtain an overview of Danish science teachers' self- perceived practices with models and modelling, their reasons for this practice, and their conditions for enacting the curriculum intentions – as well as the range among the teachers in this regard. To collect data targeted to this purpose, I decided to design an electronic questionnaire. I considered the choice of an electronic questionnaire to be an appropriate data collecting method since it not only provided me with access to a large proportion of Danish science teachers' responses but also meant it was possible to reach many teachers in a relatively less time-consuming way than other data selecting methods (e.g. interviews, observations). I also considered it a relatively limited effort for the teachers to complete the questionnaire (pilot test 10 minutes). Moreover, I perceived that a descriptive statistical analysis of the quantitative data from the questionnaire would be a relatively straightforward way to gain an overview of teachers' responses. However, to benefit from the above-mentioned affordances related to data collecting and analysis, I needed to develop the questionnaire. I will now explain in further detail how he questionnaire was developed.

Rationales for the design of the questionnaire

Several rationales guided the design of the questionnaire. *First*, I wanted quantitative data related to teachers' use, reasons and perceptions of very specific pre-defined topics. I also wished to investigate the range of teachers' responses. I therefore found it suitable to use multiple-choice questions and statements with Likert scale ratings in the questionnaire items. *Second*, realizing the limitations of pre-set categories in the multiple-choice and Likert scale questions (e.g. with respect to covering the full range of possible responses), I decided to add free statement boxes into the questionnaire. By giving teachers the possibility of making remarks and further explanations to their responses in their own terms, the data from pre-set categories would be given more breadth and depth. In addition, the free statement boxes also allowed the teachers to air their views if they felt there was something far more pressing about the issue mentioned in the pre-designed questions (Cohen, Manion & Morrison, 2007).I find this point particularly important in terms of teachers' responses to their abilities and the prospects of enacting the new competence-oriented curriculum in their teaching. *Third,* to answer the research questions, the content in the items should mirror the modelling competence framework (Figure 2.6) as well as curricular content related to models and modelling in the current curriculum. The questions should also be close to teachers' experience and classroom practice (Cohen, Manion, & Morrison, 2007). To address this rationale, I made efforts to address and unpack each of the three main elements constructing the modelling competence framework in a very concrete and understandable way and as close to classroom practice as possible. Effort was also made in terms of providing examples. For instance, the aspects of '*Predicting with models*' were formulated as: "*how often in your teaching do students' use models for predicting how a scientific phenomenon may develop e.g. during time or in different contexts?".* Along the same lines, the quite unspecific statements from the curriculum were addressed and exemplified. For instance, 'Student has knowledge of the characteristics of models in science' was addressed in this way: *"I include knowledge about models in my teaching e.g. the same phenomenon could be represented in different models or merits and restraints of models*". Another rationale guiding the design was the sequencing of the questions. For instance, I placed simple and factual questions and questions I knew the teachers were familiar with at the start of the questionnaire while more complex questions (the affordance of models related to different aspects of the curricular aims) and issues related to their own competences were placed later.

Receiving feedback on preliminary versions of the questionnaire

During the development of the questionnaire, five preliminary versions of it were commented on by representatives of various groups of people who I expected could contribute important different perspectives on it. These were: (a) 11 science teachers, (b) a central 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, (d) six science education researchers, and (e) two people from a government institution involved in in-service training of science educators.

The purpose of involving the teachers in this process was largely to get feedback on how they perceived the questionnaire in terms of its length, clarity, meaningfulness and relevance with regard to the concepts and questions in the questionnaire. More specifically, they were asked to consider the following ten questions: (1) Are you unsure about what the terms mean? (2) Can the questions be misunderstood? (3) Are the answer categories logical, and do they appropriately cover the entire issue? (4) Is there overlap between the questions? Which questions? (5) Are the questions difficult to answer? Which ones? (6) Is the questionnaire too time-consuming? (7) Do you find the questions meaningful? (8) Is your interest maintained while progressing through the questionnaire? (9) Do you think the order of the questions might interfere with the way you respond? (10) How do you find the "tone" used? Aside from getting feedback on clarity and relevance with respect to the concepts and questions in the questionnaire. the purpose of involving people from teacher training and the Ministry of Education was also to get a response to what they thought of the question in terms of covering the curriculum intentions and curricular terms adequately. People from teacher training were also involved in order to comment on how the theoretical background of modelling was reflected in the items. The main purpose of involving the group of educational researchers was to receive feedback related to the suitability of the questionnaire as a research tool.

Moreover, individuals from (a), (b) and (c) all made a number of comments to the cover letter based on the following questions: How well do you understand the text? Is the objective clear? Do you feel it immediately relevant for you to answer the questionnaire? Are you unsure about what the results will be used for?

Adjusting the questionnaire based on the feedback
In general, all individuals' and groups' comments led to adjustments to the questionnaire, particularly related to the length, formulation, order of the questions, and the terms used. In addition, the questions related to modes of models were moved up to the beginning of the questionnaire so that the teachers largely answered the questionnaire from the same understanding of what a model is. Likewise, examples of modes of models targeting each school science subject were added to enable the teachers to connect the theoretical terms to their own 'real-world' teaching experiences. Moreover, the Likert scale rating was change from four to five categories in the process. Another important change related to the wording used for the Likert scale rating and, particularly, how often the teachers used different modes of models or modelling practices. Two different sets of terms were tested: (1) Always-Very Often-Sometimes-Rarely-Never, and (2) Often-Sometimes-Seldom-Never. In both cases, teachers found it difficult to answer. To what extent and how they used models varied greatly depending on e.g. their teaching schedule, teaching subject and available teaching facilities during the semester. In addition, the teachers generally felt that the denotation on the scale was hard to use when describing the extent to which they use models in their teaching. For the same reason, the teachers stated that it was tempting to use 'sometimes'. Consequently, I decided to only denote the end values on the scale with explicit terms ('frequently' and 'never', respectively). Moreover, 'frequently' was explicitly defined as 'almost every time models were used in your teaching', in order to take into account the expressed fluctuations in the teachers' use of models over the course of a semester.

Pilot testing the questionnaire
First, I asked 34 science teachers attending an in-service course to fill in a paper version of the 5th version of the questionnaire as a pilot survey. The main purpose was to test if the Likert-scale categories were able to differentiate between teachers' responses and whether the multiple-choice options covered the whole spectrum of teachers' background information (in-service training, scheduled science lessons per week). The piolet test only resulted in minor adjustments (new scale for in-service training, more options for additional education). Second, an electronic version of the questionnaire was created in the online program SurveyXact. Finally, I asked different people from the above groups (a-e) to test the electronic version. A few items were refined in the wording and layout according to the feedback.

The final design of the questionnaire
The final version of the questionnaire can be found in Appendix 5. Please note that the questionnaire also included items not included in this project[6].

The items directly targeting models and modelling were placed at the start of the questionnaire and were divided into seven subparts:

1. Teachers' background in science teaching (prior education, in-service training, teaching experience in science and in specific science disciplinary subjects, and scheduled science lessons per week) (Q1;Q2;Q3;Q4;Q5).
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*".

[6] The questionnaire was also designed to include another smaller study related to teachers' assessment practice and their attitude to merging the current distinct science disciplinary subjects into one science subject. This study is not included in my Ph.D. project. The aspects of the questionnaire not related to models and modelling are solely included in an appendix to enhance the transparency of my sampling, and I will not address them further.

3. Variety and frequency in the way that teachers' address the three different aspects of modelling competence (content knowledge, modelling practices, meta-knowledge) in their teaching (Q9), and teachers' opinion of the learning prospects in this regard (Q11).
4. Variety and frequency of students' use of 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, supporting material, prior education, and specific school context issues (Q12), supplemented by information from the free statement box "*Please feel free to make any comments regarding the degree to which it is possible to realize the intentions in the curriculum*".
6. Teachers' opinions on 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 in the free statement box: "*Please feel free to make additional comments related to the questionnaire*" (Q17).

The 'Q' numbers in brackets refer to the order of items in the entire questionnaire.

Distribution of the questionnaire
The electronic survey questionnaire was distributed directly via email to 603 lower secondary science teachers. With one survey reminder after 7 weeks, 246 teachers employed at 153 different schools responded (40.8% response rate; n = 603), including 19 partial responses.
In the next section, I will describe how the data from the questionnaire and the school-based sub-study were analyzed.

3.6 Analysis of data

The entire data set consisted of the data shown in Table 3.1 and teachers' responses from the electronic questionnaire (Likert scale and multiple-choice responses and free box statements). The entire data set and their sources are shown in the schematic overview of the components and the process in the research design in Figure 3.5.

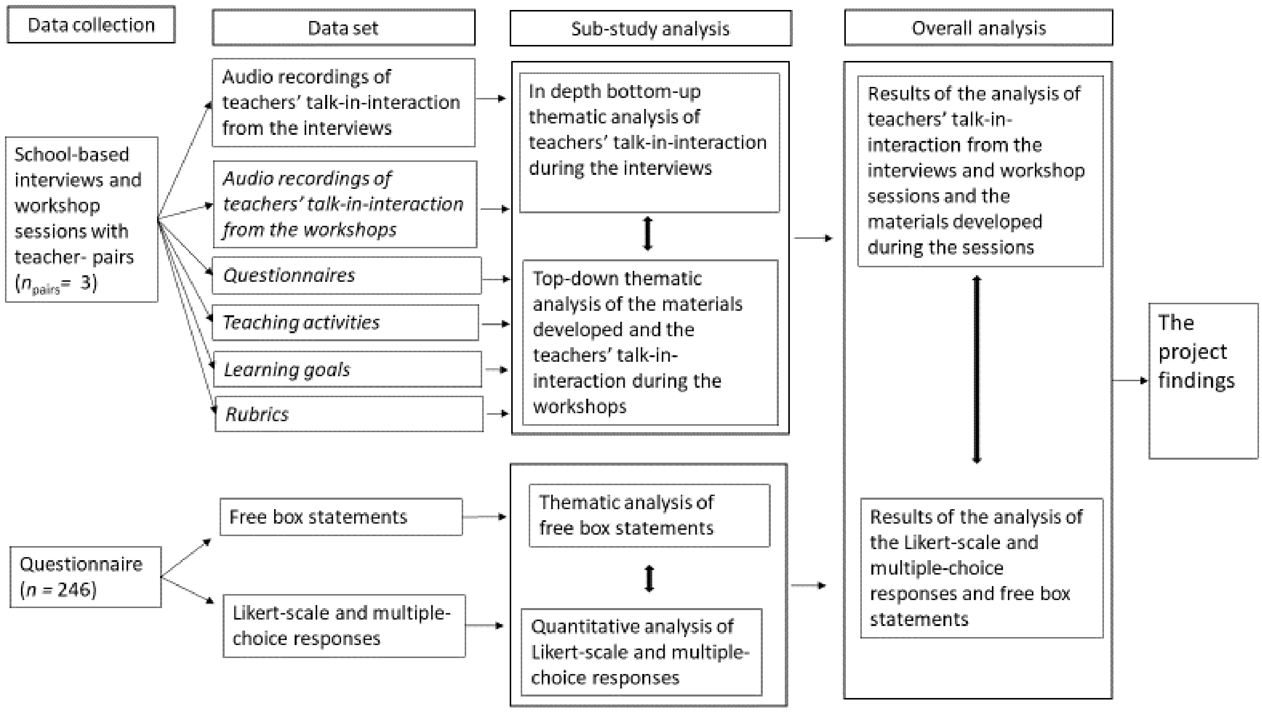

Figure 3.5 Schematic overview of the components and the process in the research design. The school-based study generated six different data sources and the questionnaire generated two. A double arrow illustrates how the components inform each other. A single arrow indicates the direction of the process. Qualitative data are shown in italics and quantitative in normal font.

While I used several analytical approaches to the data set (I will elaborate on this below) the modelling competence-oriented framework (Figure 2.6) was used as the analytical lens across the entire data set. More specifically, the framework was used across the entire data set to analyze how teachers used, and talk about the possibilities for using, models and modelling in their teaching practices. In so doing, my aim was to elucidate the alignment between the theoretical and political intentions and justifications for integrating models and modelling into teaching, on the one hand, and teachers' practices and reasons, on the other. In Figure 3.6, teachers' practices are represented by the data set and the application of the framework as an analytical lens or tool is illustrated by the hollow arrow.

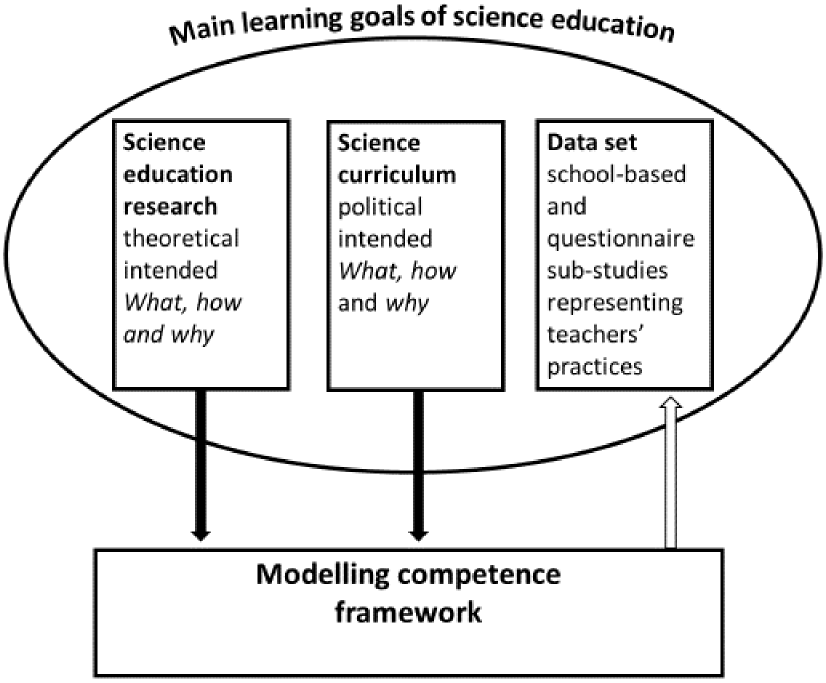

Figure 3.6 Diagram showing how the modelling competence-oriented framework was used across the entire data set to analyze teachers' use of models and modelling in their teaching practices. The hollow arrow indicates analysis and the solid arrows indicate the sources used for constructing the framework. The circle indicates how the main purposes of science education framed the relevance of aspects from the different sources to be used to inform the framework.

I mentioned above that I used several analytical approaches to the data set. My overall approach to the qualitative part of the data set (shown in italics in Figure 3.5) was to use thematic analysis (Braun & Clarke, 2006). The overall approach to the quantitative data (teachers' responses to the multiple-choice and Likert scale items, see Figure 3.5) was similarly to use descriptive statistics supplemented by inferential statistics to describe a correlation within the data (Jensen & Knudsen, 2014; Madsen, 2008). In the following sections, I will explain how the different approaches were applied in distinct ways to the different data items in the data set. First, I will describe the data analysis for the school-based sub-study and then the analysis for the questionnaire sub-study. Finally, I will explain in detail how I used the analysis of each sub-study to inform the other when aiming to answer the research questions.

3.6.1 Analysis of the data from school-based sub-study[7]

The data from the school-based study could be divided into six different data items, see Figure 3.5. The first part of my analysis was to organize the material from the workshops and transcribe the audio recordings from the semi-structured interview and workshop sessions. The posters from the workshops were used to support this process (Figure 3.3 and 3.4). The next step was to analyze all six data items by means of thematic analysis (Braun & Clarke, 2006). The aim of the analysis was

[7] The data based on the teacher who withdraw (E3) from the project are included in the data analysis, the data from the other withdrawing teachers (the first pilot team) are not. However, I still believe my experience from this work greatly informed the way I was able to manage and understand the participating teachers' approaches, actions and utterances during the project period.

to find cross-cutting, consistent and prominent themes in the six different data items. As mentioned above, the modelling competence-oriented framework was used as an overall lens across the entire data to explore what and how the different elements and aspects of the framework were reflected in teacher practices, and in teachers talk about these practices. While I analyzed all six data items by means of thematic analysis, the approaches I used for the thematic analysis were not the same. The audio recordings of teachers' talk-in-interaction from the interview sessions were analyzed in a highly detailed and in-depth manner by using an inductive bottom-up thematic analysis (Braun & Clarke, 2006) with the support of NVivo software. In this way, it was also possible to elucidate new aspects not directly captured by the modelling competence-oriented framework. For instance, this analysis provided me with information on teachers' rationales for teaching with and about models in their teaching. Likewise, the analysis provided me with information I did not address in my questions to the teachers. Some examples of this were teachers' self-perception related to teaching for modelling competence, teachers' sharing of experiences during the workshops, the way in which scientific methods were perceived as *the* scientific method or how a specific in-service course seems to influence the way in which models and modelling were treated in their teaching. If I had tried to merely fit the data into the modelling competence-oriented framework, I would not have captured this kind of information and understanding. In other words, this bottom-up approach was intended (and shown) to give me a deeper and more detailed understanding of the teachers' practice and their rationales in this regard than by simply looking at the data from a pre-existing coding frame (Braun & Clarke, 2006). In order to have a transparent, robust, and systematic analysis process, I followed Braun & Clarke's (2006) six-phase analytical tool for thematic analysis. The process is described in detail in Paper 3 (Nielsen & Nielsen, in review).

While this specific thematic analysis of the interview sessions comprised the core analytic component of the school-based sub-study, the analysis of the talk-in-interaction from the workshop sessions and the material developed during those workshops played another role in the generation of results. This relates to validity and triangulation (Greene, 2007). More specifically, when analyzing the workshop data, I used the themes found in the semi-structured interviews sessions as an 'analytic lens'. A lens used for analyzing for (a) conformity, (b) discrepancy, (c) elaboration, and (d) clarification of the themes found in the semi-structured interview sessions. The analysis of the workshop data was thus used to enrich and validate my interpretation and understanding of the analysis of the interviews. This analytic lens and the validation relationship are illustrated by the double arrow between the two thematic analysis boxes in Figure 3.5 related to the school-based sub-study.

3.6.2 Analysis of the data from the questionnaire sub-study

I analyzed all the Likert scale and multiple-choice responses with descriptive statistics on an item level (frequencies, mean scores and standard deviations). Moreover, a between-type comparison (Wilcoxon Signed-Rank Test) was used to compare possible pairs of teachers' responses to the different questions in each item dealing with the same topic (e.g. teachers' frequency in using different types of models in their teaching). All statistical analyses were performed using SPSS. For more detail, see Paper 4.

In line with the thematic analysis of the interview data from the school-based sub-study, the free box statements from the questionnaire were analyzed by means of bottom-up data-driven thematic analysis (Braun & Clarke, 2006). This open and data-driven approach seems suitable for exploring teachers' statements since the whole purpose of including the free box option in the questionnaire was to give teachers the opportunity to elaborate on the pre-designed questions and allow them to air their views and experience. In this way, the analysis of the box statements was intended to elaborate on the Likert scale and multiple-choice responses. The analysis of the latter likewise holds prospects for a better understanding of the statements in the free boxes. The different approaches to the analysis of the free box statements and the Likert scale and multiple-choice responses, as well as the relationship between the two analyses, is given in Figure 3.5. I will now expand upon how I used the analysis of each sub-study to inform the other when aiming to answer the research questions.

3.6.3 A mixed research approach to analysis of the school-based and the questionnaire sub-studies

As described in the data sampling and the analysis section above, I used different methods for data sampling as well as for the data analysis in each sub-study. The analysis from each sub-study was likewise integrated in the final step of my analysis, as illustrated in Figure 3.5 (see Paper 4 for more details). My project thus suscribes to a mixed-method research approach (Johnson & Onwuegbuzie, 2004). I found the mixed-method approach appropriate for this project since the issues to be investigated were both complex and broad in nature and therefore difficult to cover with one data sampling or analysis method. For instance, to answer the research question related to teachers' use of and reasons for how to enact modelling into their teaching, I needed a rich in-depth description based on many different sources of data. In contrast, I needed a more systematic and broader description to answer the research questions related to teachers' conditions and possibilities for enacting the modelling aspect in the current curriculum (e.g. in-service training, teaching materials, time for team meetings). In the same vein, an inductive and open approach to analyzing data related to teachers' rationales was found to be appropriate. In contrast, a more deductive top-down approach was suitable to investigate how teachers' enacting of modelling was aligned with the theoretical and curriculum intentions in this regard.

Before ending this section, I will briefly give some examples of how the mixed-methods research approach served several purposes in this project. One purpose relates to what Greene (2007) denotes the purpose of *complementarity*. In other words, I wanted to obtain a broader, deeper and more comprehensive understanding of the specific issues raised in my research questions by using methods tapping into different aspects of the research questions. For instance, to explore teachers' possibilities for enacting the intentions in the curriculum I: (a) conducted exploratory semi-structured interviews targeted at teachers' existing teaching in order to explore the gap between their practice and the curriculum intentions, (b) analyzed their teaching activities to elucidate how they interpreted and operationalized different aspects of the curriculum into what they perceive as a meaningful and manageable classroom practice, and (c) formulated questions in the questionnaire related to the teachers' self-perceived abilities to teach for modelling competence. Moreover, I also analyzed the curriculum's merits and constraints related to supporting teachers in their effort to enact modelling as a competence in their teaching.

The second purpose relates to *triangulation and validity* (Greene, 2007). In the project, I used mixed methods to enhance the validity of my research findings through methodological as well data triangulation. For instance, I used the same statements reflecting different aspects of modelling practices from the modelling competence framework (Figure 2.6) in the exploratory semi-structured interviews as I used in the questionnaire (Appendix 1 and 5). I likewise analyzed different kinds of data (teachers' talk-in-interaction, learning goals, rubrics and teaching activities) looking for how the different 'aspects of modelling practices' were reflected in the data. Moreover, the triangulation was also used to directly address the weakness of the data produced through the different methods. For instance, the questionnaire did not provide me with the opportunity to investigate whether the teachers had understood the concepts and the questions as expected. In contrast, it was possible to be responsive to the teachers' statements and interpretations of my questions during the talk-in-interaction sessions. Another example relates to generalization of the findings. Unlike the questionnaire, the findings from the talk-in-interaction sessions only had limited value for generalization purposes since they only provided me with data related to a very specific school context and a very few teachers. The last reason for using mixed-method research relates to expanding the range of the study (Greene, 2007) or, in other words, the fact that I used different methods to explore different aspects of my overall research question. For instance, I used the questionnaire to explore the extent and range of teachers' uses of different types of models. I also conducted exploratory semi-structured interviews targeted at teachers' existing and future teaching in order to explore their reasons for using models and modelling in their teaching. As described above, the use of a mix of different data sampling and analysis methods was intended to provide me with a more comprehensive understanding of teachers' practices, rationales and possibilities for teaching modelling competence than a single method could have done.

4. Ethical considerations and the role of a researcher

This section deals with some of the most important ethical considerations I encountered during my project, as well as my reflections on my role as a researcher. Some of the ethical considerations are of a general nature. I highlighted in the cover letter to the questionnaire study and in the recruitment process of teachers to the qualitative part of my study the fact that neither the schools nor the teachers would be named individually in the final report. Likewise, in cooperation with the teachers, I promised them confidentiality in relation to the school's management so that possible information or results from my research would have no negative impact on the teachers involved (collaboration difficulties among teachers involved, problematic issues in their teaching practices). Furthermore, the teachers had the opportunity to withdraw from the project if and when they wanted to. In addition, I made sure to handle any information that was not anonymized with confidentiality.

In addition to these more general ethical considerations, other considerations were related to my role as a researcher with regard to the teachers involved. Some of these teachers were my previous students and others I knew from previous projects. This meant, among other things, that the teachers were expecting to be able to continue to use me as a way of developing and obtaining input to their teaching. It was therefore sometimes difficult to find an appropriate balance between meeting this need and, at the same time, generating knowledge for my project.

There is also no doubt that the teachers became involved in the project because they knew me and therefore wanted to help. Situations often therefore arose where teachers had a clear dilemma between having to prioritize their own or the students' needs in relation to the agreements we made (time pressure, conducting teaching activities despite student conflicts, or moving too fast through learning processes so as to get through all the activities).

The dilemma between the teachers' own needs and their sense of responsibility in relation to the project was especially clear when some chose to withdraw from the project or planned meetings. There is no doubt that they found the activities demanding and that they had made many considerations for participating or not. It was also clearly that, for many of the teachers, it was a difficult decision to withdraw from the project, and they often discussed this in some depth with me. In such situations, I was put in a dilemma between the "researcher" in her efforts to collect data - and the concerns of the individual teacher.

In the same vein, I often experienced a dilemma between the need to 'examine my objectives' and take into account the needs of the teachers when planning the next lesson and their desire to manage the agenda. I find the following final quote nicely illustrates some of the above points:

"It is important that we can see ourselves in this [the project] otherwise it makes no sense for us to be here […] We are not achieving anything… We spent half an hour formulating a learning goal…

that is all well and good… in the project …and you need it for research… but in everyday life it is completely unrealistic” (B2).

5. Research validity, triangulation efforts and limitations

This section first describes how I sought to improve the internal and external validation of my findings through triangulation. I go on to outline some of the main limitations of my findings.

5.1 Validity and triangulation

Since the study was an individual Ph.D. project, a large part of the analysis was done by myself, on my own. This raises concerns as to the internal validity of the findings, particularly of the thematic data analysis, which I had no previous experience of undertaking. I made efforts to enhance the validity by asking my supervisor to participate in two of the crucial steps in the thematic analysis: (a) the matching of the initial codes to my corresponding sub-thematic descriptions (no disagreements were found between his and my matching), and (b) the process of identifying and reviewing the main candidate themes by merging the different sub-themes (also, here, no disagreements were found). Moreover, I presented and used data from my data set at seminars, workshops and as teaching materials in teacher education and I asked the participants to analyze the data (again, no disagreements were found).

The use of a mixed-method approach also served to enhance the internal validity of my findings through triangulation across sampling and analytical methods as well as across data sources (Greene, 2007). One way to enable triangulation was in the way I designed the specific sampling methods. For instance, I incorporated the same statement about the various aspects of modelling practices into the questionnaire items that I used in the semi-structured interview to obtain responses on the same questions with two different methods (Appendix 1 and 5). Another example related to how I used triangulation to address the weaknesses and strengths of the data produced through the different methods. For instance, I did not know if the respondents understood the concepts (e.g. model revision) as intended in my questionnaire, but the questionnaire gave me an overall impression of the frequency with which teachers' used model revision. In contrast, the interviews gave me an opportunity to elucidate how they understood the concept albeit only for a small number of teachers.

I also sought to increase the external validity of my findings by using different sampling methods. The findings from my school-based sub-study have only limited value for generalization purposes since the small sample size means that my findings are highly contextualized within the three specific schools and related to the five or six teachers' approaches to teaching in general and/or their personal history (e.g. in-service training, teaching experience in science, total number of science teaching subjects). In contrast, the questionnaire findings were based on almost 250 teachers from a wide range of school contexts across the country. By triangulating the findings from the school-based sub-study with the questionnaire findings, the validity of my findings increased since this increased my understanding of whether the findings in the school-based study reflected a more overall picture of teachers practice and rationale in this regard.

In my analysis, I used different approaches for triangulation. For instance, I not only analyzed the semi-structured interviews from a *bottom-up* thematic analysis but I also used the competence-oriented modelling framework as a *top-down* analytic lens in the interviews (Figure 2.6). The questionnaire responses were likewise analyzed statistically as well as by theme. I furthermore used triangulation at the data source level. For instance, I included various sources (talk-in-interaction, modelling activities, learning goals, Likert-scale items) to elucidate teachers' use of the different aspects of modelling practices. Teachers' statements in open-ended items, as well as Likert-scale responses, were also used to understand the teachers' perceptions of the possibilities of enacting the intentions in the curriculum.

5.2 Limitations

A large proportion of the data from the school-based sub-study was based on the participating teachers' talk-in-interaction about their own classroom practice. Clearly, I do not know if these talk-in-interactions depict a 'true' picture of these teachers' practice or not. For instance, the teachers could frame their narratives in a way that appears "closer" to what they are requested to do in the curriculum. However, I have several reasons to believe that the teachers intended to provide a true picture of their own practice. First, all the teachers joined the project because their intention was to develop their teaching with models and modelling by using their present teaching as a point of departure. Second, the framing of the interviews and planning workshops produced narratives very close to teachers' current and future practice, with numerous classroom examples. Finally, I also observed the teachers' classroom teaching myself and, although these observations are not analyzed or systematically used in this project, they support my overall findings. While I believe that the teachers intended to provide a true description of their actual practice, I also understand that this intention may not have been fully achieved due to their understanding of the different aspects of modelling practices (revision, design) and concepts related to meta-knowledge aspects (models' role in scientific knowledge generation). For future research, it would therefore be valuable to investigate how teachers' interpretations of practices and concepts related to models and modelling as a competence (e.g. design, revision, and nature of models) influence how they perceive of, and refer to, their own teaching practices.

An important limitation of the questionnaire method was whether the teachers had understood the concepts and the questions as expected. In retrospect, I think some of the topics addressed were probably concepts and issues that were too complex to be elucidated by a single or a few questions (teachers' rationale or teachers self-perceived competences in teaching modelling as a competence). In general, adding more questions in order to explore each issue would have qualified the survey both with respect to validation, comprehensibility, and the depth of the responses to the topics investigated (although it might have led to some fatigue on the part of the respondents). Another limitation relates to whether the teachers' responses are honest. In general, Danish teachers are severely criticized in the media. In this light, the teachers might respond to the questionnaire by painting a biased picture of doing what they are requested according to the curriculum. Efforts to avoid showing limited competence could likewise be expected.

Out of 1,796 schools contacted, only 206 provided me with email addresses. I do not know the reasons for the local school administrators' decision to respond or not to my request (e.g. protecting their teachers from additional workload; having a strong science team willing to participate; having a supportive leadership for science teaching).I also do not know if the teachers who responded did so out of a particular dedication to science, or perhaps because they were particularly interested in having their 'voice' heard, or perhaps their own children had flown the nest and they therefore had surplus time available.

Nevertheless, despite these limitations, I think that my mixed-method approach to data sampling and analysis, together with the high amount and level of detail in my study, allows me to identify some fundamentally important patterns related to Danish science teachers' practices, rationales and possibilities for achieving a teaching for modelling competence.

6. Summary of papers and implications

In this section, I provide a summary of each of the four papers that comprise this thesis. Likewise, I describe how each paper contributes to the overall aim of my Ph.D. project by elucidating different aspects of the two overarching research questions:

a) *What characterizes Danish science teachers' practices and rationales for integrating models and modelling into their teaching and how is this aligned with a competence-oriented teaching approach to models and modelling? (Paper 3,4)*

b) *What are the possibilities and challenges for teachers when adopting a curriculum based on a competence-oriented approach to models and modelling? (Paper 1, 2, 3, 4)*

The papers are diverse and aside from mirroring my learning progression they also all reflect my motivation for engaging in this Ph.D. project. With this Ph.D. project I wanted to contribute knowledge useful to solving challenges in school science with regards to teachers' possibilities for adopting curriculum intentions in their teaching. In this light, it made very good sense for me not only to write a paper targeted the research community, but also a paper targeted and useful for key persons in the process of operationalizing theoretical educational intentions to classroom practice, i.e. curriculum designers, teachers and teacher educators. Paper 1 published in the peer-reviewed Danish journal MONA reflects these intentions. Paper 2 published in the peer-reviewed ESERA Conference Proceedings Series should be perceived as an 'in progress' paper. I have chosen to include it because even though it has served as my first step to write Paper 3 (in review, Research in Science Education) and 4 (submitted, EURASIA Journal of Mathematics, Science and Technology Education), it contributes aspects of importance to answering the research questions beyond what is included in the other papers.

6.1 Paper 1: The Common Curriculum Goals and modelling competence in Biology teaching - simplification calls for interpretation [in Danish]

The first paper contributed to answering the overall research question by analysing how the format and content in the current Danish school curriculum both holds limitations and possibilities for supporting teachers in their efforts to enact modelling as a competence-oriented teaching practice. The assumption is that the prioritize, volume and descriptions of the content in the curriculum are directly related to teachers' challenges and prospects for enacting the curriculum intentions (Kind & Osborne, 2017). This also includes how the curriculum elaborates on why and how the content could contribute to accomplishing the main learning goals of science education (Osborne, 2014). This paper describes how modelling as one of four transversal competence goals has taken a prominent role in the reformed science curriculum in lower secondary science education in Denmark. Despite this prominent role, this paper's analysis of the Biology[8] curriculum show that the content and format have embedded some challenges with regards to supporting teachers in their effort to teach for modelling competence.

First, the concept of modelling as a competence is not defined, and the description of the construct of the modelling competence is formulated in general, vague and unspecific terms. Likewise, the wording and format reflect an inconsistent distinction between skills and competencies. As stated in this paper, this lack of definitions, unclear clarifications, and limited

[8] The modelling competence goal is transversal for biology, physics/chemistry and geography, and the overall descriptions of the goals are identic, and only minor differences are found in the curriculum guidelines. The differences are mainly related to the examples provided and the framing related to the specific subject-content knowledge in the curriculum. Which is not surprisingly since the working groups developing the present curriculum were requested to go for "uniformity" between all science subject in lower and secondary education with regard to the description of the four transversal learning goals (Chaiklin, 2018; Ministry of Education, 2013).

degree of detail mean that teachers are left largely on their own in the process of understanding, interpreting and unpacking: (a) what the different concepts (e.g. skill, competence) and terms (e.g. use, design, revise, evaluate) entail; (b) how the terms could be realised in a competence-oriented classroom practice; (c) identifying the relevant knowledge about models to include in a competence-oriented teaching with and about models; and (d) identifying what kind of performance is indicative when assessing students' modelling competence. None of these tasks are particularly easy, and as - demonstrated in the paper - the lack of detail and clarity in the curriculum descriptions may therefore restrict the usefulness of the curriculum with respect to teacher's work in enacting the curriculum intentions. This is especially true if teachers do not have the academic resources or time available to understand, interpret and operationalize the quite self-sufficient requests in the curriculum.

Second, the curriculum includes neither the intentions nor the arguments for how modelling as a competence can accomplish the main learning goals of science education. Again, the teachers are left alone in recognizing this link and in finding ways to operationalise it into teaching. Moreover, a part of the reformed curriculum includes a new matrix format structured around the four transversal learning goals. This new structure means that the description of main learning goals of science education is positioned detached from the descriptions of the competence goals.

Third, the wording and examples in the curriculum tend to position the descriptive use of modelling in a quite central role. By contrast, the more process-oriented approach to models and modelling, with a strong reference to the epistemic functions of models (what they are for) is described in a quite unspecified way. I argue in this paper that a more process-oriented approach (e.g. model features and use for prediction, problem-solving, discussion, question raising) would not only contribute to a more competence-oriented teaching but a stronger reference to the epistemic functions of models would also extend the prospects to teach for the three main learning goals of science education (i.e. learning science, learning about, doing science).

Fourth, the transversal learning goals (modelling, inquiry, communication and perspectivation[9]) are treated as four separate elements. This might act contrary to taking benefit of the potential of reciprocity of integrating the different elements (e.g. using models to make predictions to be tested by students' own inquiry). *Finally*, the findings of this study suggest that the curriculum only to a limited extent reflects the intended concept[10] of competence used as the theoretical backdrop for the curriculum revision. In this light, the paper suggests an interpretation of the modelling competence goal based on the above mentioned concept of competence. Moreover, the paper provides concrete examples with regard to how the concept of modelling competence could be unpacked and operationalized at the classroom level in order to use modelling as a means to accomplish the main learning goal of science education.

So, my analysis shows that the format and the content in the curriculum only provide limited support for teachers in interpreting and understanding the curriculum. Likewise, the intentions behind teaching for modelling competence is unspecified. The purpose of the reformed curriculum was to make it more simple and clear in aiming to facilitate teachers in their effort to teach for modelling competence as well as the three other transversal learning goals. As described above the general wording, their lack of definitions of key concepts, limited level of detail, unclear coherence with the main learning goals of science education, and lack of clarity, and inconsistent distinction between skills and competencies might challenge teachers' understanding and

[9] A competence largely related to the ability to contextualize and extend the content in the subject specific curriculum

[10] For more details see: (a) UVM (2010). *Introduktion til den danske kvalifikationsramme for livslang læring*. http://www.uvm.dk/Service/Publikationer/Publikationer/Uddannelseog-undervisning-forvoksne/2010/kvalifikationsramme-stor?Mode=full, and (b) UVM (2013). Forenkling af Fælles Mål. Master for forenkling af Fælles Mål: http://www.historieweb.dk/cms/upload/news_242_5449.pdf

interpretation of how to treat modelling as a competence in their teaching. Moreover, the wording in the curriculum which leans towards a descriptive use of models and modelling, the unspecified descriptions of the use and knowledge with regard to the epistemic functions of models, and the sharp division of the four competence goals in the matrix may significantly impede teachers use of the curriculum in their effort to teach for competence. This paper does not state that a curriculum with more details, examples, clarification, a more process-oriented approach, intertwining the different transversal competences, specifying the link between modelling competence and the main learning goals of science education would be sufficient to realise teachers efforts in teaching for modelling competence, but it *does* suggest that by addressing these challenges the possibilities for teachers to use the curriculum to teach for modelling competence could be substantially enhanced.

6.2 Paper 2: Prospects and Challenges in Teachers' Adoption of a New Modeling Orientated Science Curriculum in Lower Secondary School in Denmark.

The second paper contributed to answering the overall research question by identifying the key changes between the reformed curriculum that commenced in the school year 2015/16 and the previous curriculum in lower secondary science education in Denmark. The assumption is that teachers tend to interpret and assimilate new curriculum requirements into their current familiar schemes and this significantly affects how new curriculum intentions are adopted in teachers' practice (Lehrer & Schauble, 2015) and how challenged the teachers are in this regard (Crujeiras & Jiménez-Aleixandre, 2013). Moreover, this paper provides relevant background information about the Danish school context useful for understanding science teachers' possibilities for enacting the curriculum intentions.

This paper identified significant changes between the new and the previous curriculum: (a) a significant shift from perceiving knowledge and skills as separate aspects to be learned in the previous curriculum towards a competence-oriented approach framed around four main competence goals (inquiry, modelling, communication, perspectivation) addressing what students should be able to do with their skills and knowledge in the new curriculum; (b) an enhanced focus on models and the introduction of the term modelling; (c) a shift from only using models for descriptive functions (describing, communicating, explaining) towards including modelling as practices with prospects for a more inquiry- and process-oriented approach to models (comparing, designing, revising, selecting); (d) extending the features of models from only addressing visualization and simplification to also include accessibility and adjustability to different purposes.

Moreover, the new reform includes changes in the assessment format and criteria. In the previous reform the assessment was based on an individual, subject-specific, digital, multiple-choice national test and a final exam, mainly assessing content knowledge and procedural knowledge related to variable control. The new reform introduced a new final group-based, interdisciplinary oral and practical science exam assessing students' competences. However, the subject-specific national test is maintained. Likewise, a randomly selected individual, subject-specific, digital, multiple-choice final exam was introduced.

In sum this paper identified major changes in the new curriculum compared to the previous including: going beyond only using models for descriptive purposes, providing less focus on content knowledge compared to students' application of their skills and knowledge, not only addressing models as tool for visualization and simplification, and adding new ways for students to engage in modelling practices. Likewise, the reform has added new formats and criteria for assessment, while maintaining the external assessment requirements focused on root performance. Moreover, six interdisciplinary science units have been added to the subject-specific teaching. Based on the preliminary results, this paper demonstrated that the introduction of multiple large curriculum changes were a demanding task for Danish science teachers. Even though the teachers thus really would like to base their teaching on the new curriculum, it remains a tall order. This paper states that it is a huge challenge that the curriculum changes and new assessment requirements have added to an already existing problem: the mismatch between a too large curriculum and too limited time for teaching. For instance, it is very unfortunate that six interdisciplinary science units and four new competence-oriented goals have been introduced into the curriculum without at the same time proportionally reducing the time-demands for other activities such as preparing students to external assessment of root performance. To address this challenge this study among other thing suggests to work towards a better alignment between assessment and teaching approaches, and between the different assessment tests and exams; and to substantially rework the existing curriculum to match the number of teaching hours.

6.3 Paper 3: A competence-oriented approach to models and modelling in lower secondary science education: practices and rationales among Danish teachers

The third paper contributed to answering the overall research question by elucidating the alignment between the intentions and arguments for integrating models and modelling into science education, on the one hand, and teachers' practices and rationales for integrating models and modelling into their teaching practice, on the other. The assumption is that that the degree of alignment significantly affects teachers' possibilities for teaching for modelling competence. *First*, this paper outlines a theoretical competence-oriented modelling framework. This framework describes what kind of knowledge and practice related to models and modelling needs to be integrated into teaching to accomplish a competence-oriented approach. The development of the framework took account of the intentions (what and how to teach) and their justifications from two sources: the Danish curriculum and the international science education research. *Second*, this paper presents an empirical study of three teacher-teams' talk-in-interaction during a reflection session about their practices and rationales when integrating models and modelling into their teaching. The data set consists of audio recordings from the three reflection sessions, and the three posters that were produced at those sessions. The data were analysed against the backdrop of the above mentioned framework and by means of an inductive thematic analysis (Braun & Clarke 2006).

A central finding in this study is that the participating teachers' *practices* and *rationales* for integrating models and modelling into their teaching practice were characterized by a product-oriented approach. The product-oriented approach with regard to teachers' *rationales* manifested itself in several ways: (a) the enactment of models and modelling in teaching was justified as a means to communicate, explain, evaluate, and facilitate students' understanding of the science content that is the focus of the curriculum and the external assessment system; (b) the nature and function of models were solely valued as a pedagogical means to facilitate students' understanding of content knowledge, and not as a means for inquiry or problem-solving or understanding the process of modelling, and (c) while teachers did recognize that meta-knowledge aspects were important for students to understand, they deliberately deselected this aspect if the students were challenged in understanding the content knowledge. The product-oriented approach also manifested itself in several ways in teachers' *practices*: (a) the most common practice for all teachers was students' use of models for the more product-oriented practices also identified in the former curriculum (i.e. for description, communication and explanation). In contrast, the more process-oriented practices such as prediction, selection, evaluation and design were used to a lesser extent; (b) *when* process-oriented aspects of practice were enacted in classrooms, they were often enacted in a rather product-oriented fashion, for instance evaluating of models were mainly focused on whether, what and how (well) different established models represent different content aspects; (c) models were used and talked about as knowledge representations *of* the real- world, and not as artefacts *for* investigating the real world or solving a specific task; (d) the process of revising models as described in the reformed curriculum (e.g. testing a model against reality, revising or finding another model if own or others' models did not fit the referent) had no or a very limited role in teachers' practice; (e) in teachers' practice they prioritized models' descriptive features (simplifying, illustrating, visualising) over the more process-oriented (tentative, progressive), (f) in contrast to experiments, models were mainly talked about, and enacted, as the product of a scientific process rather than as part of a scientific process.

Another notable finding relates to how teachers talked about, and used, the aspects of modelling practices introduced by the new curriculum compared to the practices that were part of the former curriculum: (a) the former practises were enacted explicitly, integrated and frequently by all teachers. In contract, the new practices were enacted more implicitly, less integrated, and with very different frequency among the teachers; (b) while no teachers expressed challenges in enacting the former practices, some teachers were challenged by operationalising the new practices derived from a perceived lack of competence by the teachers themselves, a restricted understanding of the practices (designing, revision), perceived lack of guidance, and/or challenging working conditions (teaching time).

Based on the above findings, this paper argue that the participating teachers' practices and rationales for integrating models and modelling into their teaching practice are characterized by a product-oriented approach that is not aligned with the theoretical intentions and justification for teaching for modelling competence. A product-oriented approach will mainly provide students with lower-order cognitive challenges of recall, comprehension and application (Kind & Osborne, 2017). This knowledge generation is considered passive (cf. Ropohl et al., 2018) and it is not very fruitful at contributing to competence-oriented teaching where the emphasis is on reflection and on solving a specific problem or task (Nielsen & Gottschau, 2005). In the same vein, this product-oriented approach suggests the teaching mainly provides students with opportunities to engage in the descriptive functions of modelling, and it only offers limited prospects for using models for predictive and problem-solving purposes.

In addition, when models are solely introduced into the classroom as representations of what is known rather than as active tools for inquiry, students' prospects for engagement in applied scientific practice and problem-solving will be reduced (Passmore et al. 2014). With this perspective, the participating teachers' approach to models and modelling also reflects the former curriculums' approaches dominated by content knowledge of the models without developing an understanding of the processes that led to the knowledge embedded in the model, or the purposes, value and utilizations of models in science (Kind & Osborne, 2017; OECD, 2017). The findings suggest that it is not a straightforward process for teachers to interpret, understand and adopt the process of scientific modelling into their science classrooms nor to shift teachers from undertaking a product-oriented approach towards undertaking a competence-oriented approach. To enhance teachers' possibilities for teaching for modelling competence this paper stresses the need for effort in pre- and in-service training, in curriculum descriptions, and the assessment system.

6.4 Paper 4: Models and modelling: Science teachers' perceived practice and rationales in lower secondary school in the context of a revised competence-oriented curriculum[11]

The fourth paper contributed to answering the overall research question by analysing teachers' practices of, rationales behind, and perceived possibilities for, realizing the intentions of the reformed curriculum. A mixed method was used and data was generated by means of a questionnaire survey (n = 246) and audio recordings of teachers' talk-in-interaction (n = 6; in three pairs) during two kinds of session: (a) reflections on their existing practices framed as explorative semi-structured interviews, and (b) discussions about their future teaching framed as workshops. In addition, the descriptions of the teaching activities, developed during the workshops were collected. The modelling competence framework from Paper 3 was used as overall analytical lens across the entire data set.

The findings show that the teachers prioritize students' use of models for descriptive purposes related to learning content knowledge over students' engagement with modelling as a scientific practice. Specifically, the teachers significantly prioritized the modelling practices of explaining over prediction, evaluation, revision and design. Revising and designing of models based on students' own data were less frequently used than other modelling practices. A notable finding relates to teachers' restricted use and understanding of modelling as a scientific practice. As mentioned above, the dynamic process of designing, evaluating and revising models based on students' own inquiries only play a minor role in teachers' practices. Along the same lines, evaluations of students' competences in modelling were mainly directed at assessing students' models, and not their engagement in the process of modelling. While the teachers did not prioritize the scientific process with regard to modelling, the findings suggest a more process-oriented approach to experiments and other practical inquiries. Not only were experiments and other practical inquiries enacted and perceived as an important part of their teaching but the process was considered a central element in this regard. Likewise, models were mainly perceived as a result of *the* scientific method and not as a scientific method in itself. In the same line, the findings suggest that teachers predominantly used model types often described and positioned as depictions of established knowledge in textbooks and curriculum materials.

In the paper it is argued that teachers' predominant use of descriptive modelling practices could reflect the fact that they take up the same descriptive role of models as positioned in their teaching material, and this might be counterproductive to a more process-oriented approach to models and modelling. While the descriptive use of models is an important element in science teaching, this paper states that it is not sufficient in a competence-oriented teaching. It is argued that this kind of teaching also needs to include the process of science (doing science) and knowledge of this process (about science).

The paper also states that teachers' prioritization of students' learning with respect to the three main learning goals of science education (i.e. learning science, learning to do science, learning about science) influence how they treat models and modelling in their teaching. The study shows that the teachers have a tendency to relate 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

[11] Based on the suggestions and comments of the reviewers the submitted version of the paper was revised only to include the questionnaire survey and consequently retitled to "Models and Modelling: Science Teachers' Perceived Practice and Rationales in Lower Secondary School in the Context of a Revised Competence-Oriented Curriculum.

with scientific methods in science or to contribute to students' understanding of how science contributes to knowledge-generation in science. This tendency to view the affordance of models as facilitating students' learning of content knowledge was also reflected in the teachers' treatment of models in their teaching.

While the findings in this way indicate a gap between teachers' practices and rationales on the one hand, and the curricular intentions on the other, the findings also suggest some very specific challenges perceived by the teachers in adopting the new curriculum. These challenges are: (a) lack of time for preparation, teamwork and teaching, (b) shortage of clarifications and examples in the curriculum materials, particular with regard to assessing students' competences in modelling, (c) shortage of teacher education and in-service training how to adopt modelling in practice, (d) overcrowded curriculum and fragmented teaching time with students, and (e) lack of alignment between assessment and teaching approaches, and between the different assessment tests and exams.

While the findings in this way indicates a large range of challenges encountered by the teachers when requested to transform the new curriculum into practice, the findings also suggest further potential actions that could be taken to begin to narrow the gap between teachers' practices and curricular intentions. For instance, the paper suggests that teachers' restricted perceptions and use of modelling as a scientific practice could be changed towards a more process-oriented treatment by combining modelling with well-established practice around experiments, observations and laboratory work. Likewise, the paper suggests future actions to use the untapped potential in teachers' knowledge sharing and teachers' perceptions and valuing of having a strong and supportive network of science colleagues.

6.5 Implications

With this Ph.D. project I hoped to elucidate what science teachers are doing when they adopt the intended curriculum to teach for modelling competence, as well as their rationales for doing what they are doing. The assumption was that the degree of alignment between teachers' practices, rationales and possibilities for integrating models and modelling into teaching, on the one hand, and the theoretical and political intentions, on the other, significantly affects the prospects of and challenges for teachers in adopting a competence-oriented modelling teaching practice. While my results demonstrate a "gap" in this alignment, my findings suggest multiple potential actions that could be taken to begin bridge this gap. If we want to bridge this gap, we have to consider the challenges and possibilities on each side.

My study highlights the following areas for consideration:

(a) In-service and pre-service educators. My findings suggest that, if teachers could identify elements in their existing practice that could be extended with new modeling aspects of teaching then this would be more relevant and manageable, as opposed to enacting entirely new aspects of modelling that do not resemble their existing practice at all. In this light teachers' well-established modelling practices and rationales could be utilised by extending them through introducing minor adjustments that would make teachers' practice more process-oriented. Likewise, it should be clearly justified for the teachers how these adjustments aid in facilitating students' learning of content- *and* meta-knowledge. While the teachers in my study did not prioritize the scientific process with regard to modelling, they did have another approach to experiments and other practical inquiries. Not only was this kind of activity enacted and perceived as an important part of their teaching but the process was considered a central element in this regard. Based on this, my findings

suggest that teachers' restricted perceptions and use of modelling as scientific practice could be addressed by combining modelling with well-established practice around experiments, observations and laboratory work.

This could, for instance, be undertaken through:

- Students' use of established models to inform their questions and hypotheses to be tested by means of experiments;
- Students crafting of testable predictions based on models representing students' own ideas about a phenomenon;
- Students crafting testable predictions based on established models representing core causal explanations related to the curriculum content knowledge;
- Students' empirically testing sub-processes in models against own data form observations or experiments, field- or laboratory observations;
- Students' evaluating and revising their own 'table models' or tentative 2D models based on empirical data, new theoretical considerations, advanced learning or new purposes;
- Students' considerations of what and how to represent their data using different types of model; and students' comparing and evaluating of each other's models representing the same referent but based on different ideas about the referent, different kinds of data or different tasks to be solved.

Such efforts would not only add to a more process-oriented approach to models and modelling but they would also raise awareness among teachers about how models are used as an inquiry tool in science to make sense of the world. Likewise, the use of models as representing content knowledge could help students to connect laboratory work with theoretical knowledge and, at the same time, enrich the way in which teachers perceive *the* scientific method. Moreover, the use of models as artefacts for inquiry would go beyond the conventional use of models in science teaching for describing and explaining by representing important aspects of modelling as a scientific practice. This suggested approach has the potential to facilitate students' development of subject-specific knowledge, modelling practices, and meta-knowledge *by intertwining all three elements* in an applied use targeted a specific task and, in this way, resonates well with the three main learning goals for science education (e.g. learning science, doing science and learning about science).

In the same line, teachers' existing practice of comparing and evaluating multiple models could be a good starting point. This could be done by channelling teachers' existing descriptive use of multiple models towards a more process-oriented model *for* practice that focuses on multiple models' affordances in raising, answering, predicting or solving different ideas, tasks and problems.

Finally, the findings suggest that, when teachers are given the opportunity to reflect and plan together, they not only exchange concrete teaching ideas but also add to each other's understanding of more central issues related to the perception of modelling as a competence. 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 teaching. My findings also suggest that obtaining input from outside contributes to development and reflections in this regard.

(b) Curriculum designers. My findings also suggest curriculum designers to consider: (a) adapt the existing curriculum to match the number of teaching hours (or *vice versa*); (b) position and specify modelling as a scientific practice equal to *the* scientific method; (c) operationalise modelling

competence to a greater detail; (d) emphasise the predictive nature and role of models; (e) highlight how students' understanding of content- *and* meta-knowledge could be facilitated through a purposeful, task- and problem-oriented engagement with models; (f) and reconsider how to ease teachers' understanding of the curriculum intentions through clarifying concepts, providing examples and highlighting how models and modelling can accomplish the overall aim of science education.

(c) *Policy-makers*. It is recommended that educational policy-makers ensure better alignment between external tests and exams, and between external assessments and curriculum intentions; and recognize that macro-level changes to curricula do not emerge in teaching by themselves unless substantial support is provided.

Finally - and perhaps most importantly - teachers have different experiences and conditions for teaching for modelling competence. There is therefore no 'one-size-fits-all' recipe for how to reduce the gap between the curricular intentions and teachers' practice.

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8. Included papers

Paper 1

Nielsen, S.S. (2015). *Fælles Mål og modelleringskompetence i biologiundervisningen – forenkling nødvendiggør fortolkning* (The Common Curriculum Goals and modelling competence in biology teaching - simplification calls for interpretation). *MONA*, 4, 25–43. [In Danish].

Fælles Mål og modelleringskompetence i biologiundervisningen

– forenkling nødvendiggør fortolkning

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Abstract: *Artiklen beskriver hvilke kvaliteter og begrænsninger de nye Forenklede Fælles Mål indeholder i forhold til at understøtte lærernes arbejde med at implementere modelleringskompetencemålet for biologifaget i folkeskolen. Der gives et bud på hvordan modelbegrebet og modelleringskompetencemålet i de nye Forenklede Fælles Mål kan fortolkes når modeller og modellering skal inddrages kvalificeret i undervisningen. Artiklen problematiserer hvordan indholdet og formatet i de nye Forenklede Fælles Mål understøtter lærernes arbejde med at kvalificere brugen af modeller og modellering i undervisningen. Desuden gives der konkrete eksempler på hvordan modelleringskompetencemålet kan udfoldes og omsættes til undervisningspraksis så der bliver sammenhæng mellem biologifagets formål, modelbegrebet og modelleringskompetencemålet.*

Introduktion

Fælles Mål er udarbejdet med henblik på at understøtte lærernes arbejde med at få omsat de lovmæssige intentioner i folkeskoleloven til praksis i skolen (UVM, 2014a). Der sker løbende en revidering af Fælles Mål. Den seneste udgave, de nye Forenklede Fælles Mål, skal implementeres på alle skoler fra august 2015 (UVM, 2014b).

Baggrunden for den seneste revision er bl.a. Danmarks Evalueringsinstituts undersøgelse af læreres brug af Fælles Mål. Undersøgelsen viste at Fælles Mål kun anvendes i begrænset omfang i den daglige praksis (Danmarks Evalueringsinstitut, 2012). Derudover pegede undersøgelsen på at lærernes planlægning og tilrettelæggelse af undervisning ikke er præget af tænkning om læringsmål som styrende for undervisningen (ibid.).

Formålet med ændringerne var at formulere målene så enkelt og klart at de bliver lettere at anvende som didaktisk planlægningsredskab, og herigennem at understøtte at lærernes undervisning bliver mere målstyret (Dolin, 2014).

Forenklingen af Fælles Mål betyder dog også at ansvaret for fortolkningen af Fælles Mål i vid udstrækning er lagt ud hos den enkelte lærer eller det enkelte lærerteam. Det er derfor interessant at undersøge hvordan indholdet og formatet i de nye Forenklede Fælles Mål enten kan bidrage til eller udgøre en barriere for at lærerne kan omsætte intentionerne til praksis.

Forenklede Fælles Mål – forskrifter og vejledning til læreren

De nye Forenklede Fælles Mål (herefter: FM) indeholder fagets formål, en læseplan og en vejledning. Derudover indeholder FM en oversigtsmatrix som beskriver fagets kompetenceområder og kompetencemål samt fagets færdigheds- og vidensmål (UVM, 2014b). Fagformålet og læseplanen inkl. kompetencemålene er det lovmæssige grundlag for lærerens undervisning. Derudover stiller Undervisningsministeriet en række understøttende tiltag til rådighed, bl.a. oplæg, kurser og supplerende materiale på hjemmesiden EMU Danmarks læringsportal (www.emu.dk). Denne artikel forholder sig til det lovmæssige grundlag og vejledningen. For en uddybning af de andre tiltag henvises til kommentarindlægget "Udvikling og forankring af ny undervisningspraksis tager tid" (Nielsen, 2015).

Ifølge FM skal der nu i biologi og i skolens andre naturfag ud over de fagspecifikke mål også arbejdes med fagenes praksis inden for de fire kompetenceområder: undersøgelse, modellering, perspektivering og kommunikation (UVM, 2014b). Hvert af disse kompetenceområder består af et overordnet kompetencemål og en række underliggende progressionsopdelte færdigheds- og vidensmål (figur 1).

Fagenes praksis er i FM kendetegnet ved de arbejdsmetoder, processer og tankegange som er fælles for alle skolens naturfag, fx modellering.

Modellernes potentialer i forhold til undervisning og læring

Modeller og modellering er centrale kendetegn for naturvidenskaberne og rummer potentialet til at integrere fagets andre praksisser (Lehrer & Schauble, 2015), fx undersøgelse, perspektivering og kommunikation. Det er imidlertid udfordrende for både elever og lærere at arbejde med modellering i naturfagsundervisningen (Schwarz et al., 2009).

Inddragelse af modellering i undervisningen har betydning for elevernes erkendelse af hvorledes naturvidenskaberne skaber og formidler viden. Derudover peger empiriske undersøgelser på gode læringspotentialer i forhold til elevernes begrebs- og

Kompetence-område	Overordnet kompetence-mål	Fase	Færdigheds- og vidensmål	
Modellering	Eleven kan anvende og vurdere modeller i biologi.	1	Eleven kan anvende modeller til forklaring af naturfaglige fænomener og problemstillinger i naturfag.	Eleven har viden om modellering.
		2	Eleven kan vælge modeller efter formål.	Eleven har viden om karakteristika ved modeller i naturfag.
		3	Eleven kan vurdere modellers anvendelighed og begrænsninger.	Eleven har viden om vurderingskriterier for modeller i naturfag.

Figur 1. *Eksempel fra biologifagets Fælles Mål på et af de fire kompetenceområder og forskellige måltyper. De tre faser henviser til en indbygget progression i færdigheds- og vidensmålene (UVM, 2014b).*

sammenhængsforståelse samt elevernes forståelse for og brug af naturvidenskabelige arbejdsmetoder og tankegange (Nicolaou & Constantinou, 2014).

Der er altså relevante begrundelser for at inddrage modeller og modellering i naturfagsundervisningen. Forståelsen af de to begreber har imidlertid stor betydning for hvorfor og hvordan modeller og modellering bliver anvendt i en undervisningskontekst.

Modelbegrebet og modellernes funktion i undervisningen

Modeller og modellering defineres ikke i FM. Det er derfor op til den enkelte lærer at tolke og udfolde begrebet. Dette kan være problematisk da lærernes tolkning og dermed også forståelse af begreberne har stor betydning for hvordan modelleringskompetencemålet bliver omsat til praksis (Krell & Krüger, 2015).

Internationale undersøgelser peger på at modeller (a) i høj grad tolkes som kopier eller idealiserede beskrivelser af virkeligheden af både lærere og elever, (b) primært anvendes i undervisningen for at vise eller forklare naturvidenskabelige fænomener eller objekter og (c) sjældent bliver sammenlignet, evalueret eller ændret gennem elevaktiviteter (Krell & Krüger, 2015; Oh & Oh, 2011).

Ovenstående peger på at lærerne i høj grad tolker modeller som et statisk produkt og i mindre grad forholder sig til modeller som vidensgenererende, kumulative og i fortsat udvikling. Tolkningen kan være problematisk i en undervisningskontekst da den afspejler modeller som et statisk beskrivende billede af virkeligheden. Det kan bidrage til at bekræfte elevernes generelle fejlopfattelse af modeller som statiske og tro kopier af naturen (Grünkorn et al., 2014). Læseplanen og vejledningen i FM forholder sig til ovennævnte problemstilling og fremhæver at der skal arbejdes med elevernes evne til at skelne mellem virkelighed og model.

Hvis lærerne primært har fokus på modellernes forklaringsværdi, kan det reducere modellernes potentiale til at udvikle elevernes naturfaglige kompetencer. Det skal forstås således at læringen i biologifaget gennem modeller primært bliver et spørgsmål om elevernes evne til at kunne forklare begreber og sammenhænge samt anvende praktiske færdigheder til modelkonstruktion.

Det kan betyde at der i undervisningen vil blive mindre opmærksomhed på hvilken rolle modeller spiller som proces, som metode og som redskab til at svare på nye spørgsmål. I værste fald kan det bidrage til en (mis)forståelse af videnskabs- og biologifaget som statiske vidensprodukter frem for en kumulativ proces.

Som nævnt indeholder FM en oversigtsmatrix der beskriver fagets kompetenceområder og mål. Oversigtsmatrixen har en central placering på EMU's hjemmeside og findes desuden i en Excel-version så den direkte kan eksporteres til en årsplan eller elevplan. Mit gæt er at oversigtsmatrixen vil blive lærernes centrale planlægningsværktøj når de arbejder med FM. Matrixens indhold og lærernes tolkning af formuleringerne spiller derfor en central rolle i forhold til hvordan modelleringskompetencemålet bliver omsat til praksis.

Formuleringerne i FM-matrixen kan let fortolkes som et udtryk for en relativt produktorienteret brug af modeller og modellering i undervisningen med fokus på modellernes forklaringsværdi. I UVM's første matrixudgave skulle eleverne "udvikle" og "udvælge" modeller. Ifølge den reviderede udgave skal eleverne kun "vælge" modeller (UVM, 2014b), og der er primært fokus på at eleverne skal bruge modeller til at beskrive og forklare naturfaglige begreber og sammenhænge. Det gælder både når de anvender, vælger og vurderer modeller. Det afspejles fx i formuleringerne af matrixens 12 fagspecifikke færdighedsmål. Her bruges verbet "forklare" 11 gange og "vurdering" en gang. I forbindelse med modellering nævnes verberne "udvikle" og "ændre" ikke i matrixen, men alene i læseplanen og vejledningen.

Ifølge læseplanen skal elevernes vurdering af modeller ligeledes knyttes til modellernes anvendelighed i forhold til at kunne synliggøre og forklare naturfaglige forhold. Vejledningen har primært fokus på modellernes forklaringsværdi, men den åbner dog samtidig op for en mere procesorienteret tilgang til modeller. Fx nævnes at eleverne kan teste en model mod virkelige processer og ændre i modellen eller finde en anden og bedre model hvis der er uoverensstemmelse med virkeligheden.

Baseret på ovenstående betragtninger sammenholdt med de tidligere nævnte undersøgelser af lærernes forståelse og brug af modeller mener jeg at der er en reel fare for at lærerne vil omsætte formuleringerne i FM til en undervisningspraksis som prioriterer modellernes forklaringsværdi højt, og at det finder sted på bekostning af en mere procesorienteret tilgang til modeller. Der er dermed en risiko for at der ikke bliver fokus på modellernes procesegenskaber til fx at opstille hypoteser og problemformuleringer, valg af variabler, tolkning af observationer og undersøgelsesdata, vidensgenerering, -deling og -diskussion.

Procesorienterede modelaktiviteter kan bidrage til elevernes epistemologiske forståelse

I den nuværende udformning af FM er fagets epistemologi udelukkende placeret under kompetenceområdet perspektivering. Procesorienterede modelaktiviteter har imidlertid oplagte potentialer til at bidrage til elevernes epistemologiske forståelse gennem elevernes egne erfaringer. Det kan fx ske gennem modelaktiviteter som drager nytte af modellernes egenskaber til fx forudsigelse og hypotesedannelse. Eleverne kan også diskutere hinandens modeller og derefter udarbejde en konsensusmodel. Det vil også være oplagt at eleverne udvikler deres egne modeller på baggrund af egne observationer. Eleverne vil herved få en praksisbaseret forståelse for at modeller er en tolkning af virkeligheden og i høj grad kan være personafhængige. Aktiviteterne vil også åbne op for en generel diskussion om modellers status, muligheder og begrænsninger.

Hvis undervisningen primært har fokus på produkt frem for på proces, kan det begrænse de potentialer modeller har til at bidrage til opfyldelse af formålet med biologifaget. Formålet fremhæver netop at eleverne skal opnå indblik i hvordan biologi og biologisk forskning kan bidrage til vores verdensforståelse, samt erkende at naturvidenskab er en del af vores kultur. I forhold til fagets formål (UVM, 2014b) og det naturfaglige kompetencebegreb (Dolin et al., 2003) kan man derfor argumentere for at der i undervisningen bør arbejdes med et modelleringsbegreb som inkluderer forskningens epistemologi. Hermed menes at elevernes arbejde med og om modeller også bør omfatte centrale processer der foregår i videnskabelig forskning. Fx modellernes funktion i forhold til kommunikation, forklaring, forudsigelse samt idé- og vidensgenerering. Herved bliver der også mulighed for at arbejde med et modelleringsbegreb der både indbefatter modeller som produkt og som proces. Derudover bliver der mulighed for at udnytte den synergieffekt det har at arbejde integreret med flere af kompetencemålene, fx kommunikation, modellering og undersøgelse.

Modeltyper og vurderingskriterier

Det er svært for lærerne at se læringspotentialerne og -udfordringerne i de forskellige modeltyper (Justi & Gilbert, 2003). FM giver en række eksempler på forskellige modeltyper som kan indgå i undervisningen. Der er imidlertid ingen systematisk opdeling af de nævnte modeltyper. Ifølge FM skal eleverne kunne vurdere naturfaglige modellers anvendelighed og begrænsninger (figur 1). FM uddyber dog ikke hvilke vurderingskriterier der kan være relevante i forhold til modellernes forskellige formål og egenskaber. Eksempelvis har formålet betydning for hvilke puljer, processer og relationer der repræsenteres gennem en model over kulstoffets kredsløb.

En systematisk opdeling af modellerne og en konkretisering af vurderingskriterierne kunne sandsynligvis bidrage til en bedre forståelse af hvorfor, hvordan og hvornår de forskellige modeller kunne inddrages i undervisningen. I forhold til progression ville det fx være relevant at opdele og vurdere modellerne efter kompleksitet, abstraktionsniveau og forklaringsværdi.

En konkretisering af vurderingskriterierne for modeller ville også understøtte lærerens arbejde i forhold til at give formativ feedback når eleverne arbejder med at vurdere egne eller andres modeller.

Modelleringskompetencemålet er beskrevet i generelle vendinger

FM er modelleringskompetencemålets tilhørende færdigheds- og vidensmål opdelt i tre faser (figur 1). Beskrivelsen af faserne og modelleringskompetencemålet er meget overordnet. Det kan være en fordel da det åbner op for lærerens mulighed for fortolkninger og tilpasninger. Fx kan undervisningen i høj grad planlægges i forhold til elevforudsætninger, elevernes medbestemmelse, arbejdsformer og skolebaserede indsatsområder.

Hvordan modelleringskompetencemålet og faserne udfoldes i praksis, er imidlertid meget afhængig af hvordan den enkelte lærer fortolker de tre faser og modelleringskompetencemålet. Fx kan begrebet "anvende" i fase 1 fortolkes og udfoldes meget forskelligt.

Jeg har formuleret nedenstående eksempler for at illustrere variationsbredden i fortolkningsmulighederne.

Eleverne skal kunne anvende modeller til:

- At beskrive hvordan et objekt eller fænomen ser ud: Eleverne kan fx beskrive hvordan et glukosemolekyle er opbygget, vha. et molekylesæt, eller beskrive befolkningssammensætningen i et bestemt land vha. en befolkningspyramide.

- At forklare hvordan et fænomen opstår: Eleverne kan fx forklare hvordan dag og nat opstår, vha. en animationsmodel af Jordens rotation om sin egen akse.
- At forklare hvordan et fænomen er i overensstemmelse med empiri eller teori: Eleverne kan fx forklare sammenhængen mellem den kemiske formel for fotosyntesen og en grafisk afbildning af plantevækst baseret på elevernes egne forsøgsresultater med bygplanter.
- At forudsige et fænomen: Eleverne kan fx forudsige hvordan en reduktion i afbrænding af fossile brændstoffer eller genplantning af skov vil påvirke CO_2-indholdet i atmosfæren, baseret på en computerbaseret interaktiv model. Eller eleverne kan forudsige en sandsynlig fremtid for en befolkning ud fra befolkningspyramider.
- At forklare det samme fænomen vha. flere forskellige modeller: Eleverne kan fx forklare kulstoffets kredsløb vha. forskellige modeller tilpasset forskellige formål. En model kan fx repræsentere kredsløbet på (plante)individniveau med fokus på opbygning af organisk stof. En anden model kan repræsentere kredsløbet på samfundsniveau med fokus på puljer, processer og sammenhænge i forhold til klimaforandringer.
- At illustrere hvordan modeller ændres når nye teknikker og viden udvikles: Eleverne kan fx analysere forskellige historiske modeller af genetik og arvelighed.
- At planlægge en undersøgelse: Eleverne kan fx få idéer til relevante variabler til et laboratorieeksperiment eller centrale målparametre til en naturundersøgelse ud fra en model.
- At evaluere egen læring: Eleverne kan fx følge udviklingen i deres egen læring når de løbende reviderer deres modeller baseret på ny viden og færdigheder.

Ovenstående eksempler viser variationsbredden i fortolkningsmulighederne af FM og måske også intentionerne i FM. Men eksemplerne illustrerer samtidig at det i høj grad er lærerens fortolkning som har betydning for hvordan modellernes potentiale i forhold til undervisning og læring udnyttes.

Derudover har lærerens tolkning stor betydning for hvilke evalueringskriterier elevernes modelleringskompetence bliver vurderet ud fra. Er det fx (a) elevernes kompetencer til at anvende modeller som metode til at forudsige hvordan et fænomen vil udvikle sig? Eller er det (b) elevernes kompetencer til at anvende modeller til at beskrive et naturfagligt fænomen der skal evalueres?

Hvis beskrivelserne i FM skal bruges som planlægnings- og evalueringsværktøj, vil det som minimum kræve at læreren forstår intentionerne, variationsmulighederne og evalueringskriterierne i de enkelte faser. Den manglende detaljeringsgrad og tydelighed i fasebeskrivelserne kan derfor være en barriere for lærerens arbejde. Det gælder især hvis læreren ikke har de faglige og tidsmæssige ressourcer det vil kræve at fortolke og omsætte modelleringskompetencemålet til praksis. Dette arbejde vil kræve at læreren eksplicit kan formulere mål og evalueringskriterier for de forskellige faser i de enkelte undervisningssekvenser.

En mere detaljeret beskrivelse af modelleringskompetencemålets faser vil derfor være et godt supplement til FM i forhold til at støtte læreren i dette arbejde. Beskrivelsen kan fx indarbejdes i den eksisterende vejledning. Det supplerende materiale på EMU-hjemmesiden vedr. biologifaget bør ligeledes beskrive flere (og mere nuancerede) eksempler på hvordan de forskellige faser kan omsættes til praksis når eleverne arbejder med modeller.

Er progressionen i modelleringskompetencemålet logisk?

Strukturen i matrixen og formuleringerne i læsevejledningen signalerer en indbygget progression i de tre faser i figur 1. Eleverne skal først kunne anvende modeller, derefter skal eleverne kunne udvikle og udvælge modeller – og til sidst skal eleverne kunne vurdere modeller. Beskrivelsen af den indbyggede progression kan være problematisk hvis læreren tolker beskrivelsen i FM som en forskrift på hvordan brugen af modeller og elevernes læring forventes at følge en bestemt fastlagt progression i undervisningen. Ofte vil undervisningen være en vekselvirkning mellem de forskellige progressionsniveauer.

Dertil kommer at elevernes læring ikke altid kan forventes at følge en forudbestemt lineær proces. Derudover har lærerens formål med at anvende modeller i en konkret undervisningssituation betydning for om det fx er oplagt at starte med udvikling eller med vurdering af modeller. Fx kan det være oplagt at eleverne vurderer forskellige modellers egenskaber til at forklare en specifik problemstilling som de skal undersøge inden de selv skal udvikle en model.

Som tidligere nævnt er de tre faser kun beskrevet meget overordnet. Man kan derfor argumentere for at progressionsmulighederne i et tænkt undervisningsforløb inden for én af de tre faser (fx "anvende") kan være mindst lige så store som progressionsforskellen mellem de tre faser (fx "anvende" og "vælge"). Begrebet "anvende" kan fx indeholde følgende progressionsforløb: Eleverne starter med at beskrive sammenhængen mellem temperatur og luftfugtighed vha. en model. Herefter skal eleverne forudsige ændringer i luftfugtigheden over et døgn i forskellige landskabstyper baseret på samme model og deres egne temperaturmålinger.

I matrixens fastlagte progression nævnes "anvende" før "vælge". Det er dog ikke altid den mest logiske rækkefølge i en undervisningskontekst. Fx kan det godt kræve mere indsigt at anvende en model til forudsigelse af et komplekst naturfagligt fænomen (fx klimaforandringer) end den indsigt det kræver at vælge en model der illustrerer opbygningen af et simpelt organ.

Som illustreret i ovenstående vil den indbyggede progression i de tre faser ikke altid være i overensstemmelse med den progression som findes i et undervisningsforløb. Matrixens progressionsopdelte faser kan derfor være problematiske hvis læreren i sin tolkning og undervisningspraksis altid sætter lighedstegn mellem målprogressionerne og undervisningsforløbets progression.

Over et længerevarende uddannelsesforløb kan den beskrevne progression måske give mening. Men om progressionen som den beskrives i FM, er meningsfuld, er både afhængig af: (i) lærerens forståelse af de generelle fasebeskrivelser og deres indbyrdes forhold og (ii) lærerens fortolkning af hvordan faserne skal omsættes til praksis. Derudover er det vigtigt at være opmærksom på at relevansen af den fastlagte progression i de tre faser ikke er indholds- eller formålsneutral.

Gensidighed og synergieffekt mellem naturfagenes praksis og den fagspecifikke viden

Internationalt er der de senere år sket et skift i tilgangen til naturfagsundervisningen. Udviklingen er gået fra en opdelt til en mere integreret opfattelse af undervisningen og læring. Tidligere har der i høj grad været fokus på *enten* udvikling af elevernes faglige begrebs- og sammenhængsforståelse *eller* elevernes færdigheder til at bruge naturvidenskabelige arbejdsmetoder og tankegange. Dette er i en dansk kontekst kommet til udtryk gennem opdelingen i henholdsvis videns- og færdighedsmål i FM (UVM, 2014b). I modsætning hertil er der i dag mere fokus på en mere integreret karakteristik af naturvidenskab i skolen som en "praksis" (Lehrer & Schauble, 2015). Begrebet praksis anvendes i denne artikel ud fra et epistemologisk perspektiv, forstået som en beskrivelse af hvordan viden bliver udviklet og revideret inden for naturvidenskaben (*ibid.*). Dvs. der i højere grad er fokus på at eleverne producerer viden med fagets metoder (fx modellering) frem for adskilt at lære dem fagets på forhånd producerede viden og fagets arbejdsmetoder. Dette er også i tråd med biologifagets udvikling mod en mere undersøgelsesbaseret og "scientific-literacy" orienteret tilgang til læring (Hansen, 2007).

Skiftet i retning af at lade eleverne arbejde med autentiske arbejdsformer og lade dem producere viden med faget kan i høj grad også udnytte den gensidighed der findes mellem naturfagenes praksis og den faglige viden (Manz, 2012). Fx vil elevernes praksis med at planlægge en feltundersøgelse ud fra en model tage afsæt i deres eksisterende viden om biotopens økosystem og feltmetoder. Eleverne kan gennem arbejdet udvikle deres viden og færdigheder relaterede til biotopen og de anvendte feltmetoder. Derudover kan eleverne gennem arbejdet opnå en øget forståelse for modeller som en praksis. Det er en praksis hvor modeller fx bruges til at planlægge og forudsige naturfaglige undersøgelser, give ny viden om undersøgelsesfænomenet samt forklare undersøgelsesresultater – og evt. revidere modellen på basis af resultaterne.

FM fremhæver at de fire kompetencemål, herunder modelleringskompetencemålet, skal kombineres med fagets fagspecifikke færdigheds- og vidensmål. Dette er i fin overensstemmelse med ovenstående betragtninger og internationale strømninger. Men det er imidlertid ikke uvæsentligt hvordan modelbegrebet forstås og dermed også anvendes i denne kombination.

Hvis kombinationen af modelleringskompetencemålet og fagets fagspecifikke mål skal bidrage til (a) en mere integreret karakterisering af naturvidenskab i skolen som en "praksis" og (b) udnytte den gensidighed der findes mellem naturfagenes praksis og den fagspecifikke viden, bør undervisningen tage udgangspunkt i et modelbegreb som ikke kun inkluderer modellernes funktion i forhold til forklaring. Modellernes funktion i forhold til kommunikation, diskussion, forudsigelse samt idé- og vidensgenerering bør også inddrages hvis kombinationen skal udnyttes optimalt.

Som tidligere nævnt har FM en tendens til at vægte modellernes forklaringsværdi frem for modellernes egenskaber til at forudsige og generere ny viden. Dette kan være uhensigtsmæssigt i forhold til at udnytte den gensidighed og synergieffekt der ligger i at arbejde integreret med fagenes praksis og faglige viden.

Kompetencebegrebet og Fælles Mål

Som tidligere nævnt beskriver FM modelleringskompetencemålet i meget generelle termer (figur 1). Derudover fremgår det ikke entydigt af FM om modelleringskompetencemålet udelukkende er en beskrivelse af naturfagenes faglige kerne, eller om formålet er af mere dannelsesmæssig karakter. Udfordringen med at operationalisere modelleringskompetencemålet bliver ikke nemmere af at selve kompetencebegrebet er et uklart og omdiskuteret begreb der anvendes i mange betydninger.

Det er derfor relevant at undersøge: (a) hvilken forståelse af kompetencebegrebet der ligger til grund for udformningen af FM, og (b) hvilken betydning denne forståelse har hvis den overføres til modelleringskompetencemålet når sidstnævnte skal omsættes til en undervisningspraksis som kan bidrage til at opfylde fagets formål.

Modelleringskompetencemålet omsat til undervisningspraksis

Rammen for FM har været "Den danske kvalifikationsramme for livslang læring". Her defineres kompetencer som: "*Kompetencer er den bevidste evne til at anvende viden og færdigheder i en given kontekst …*" (UVM, 2010). Derudover er der udarbejdet en "master" for udformningen af de konkrete FM som er en skabelon for hvordan målbeskrivelsen skal udformes i de enkelte fag (UVM, 2013). Masteren indbefatter bl.a. en afklaring af de grundlæggende begreber fra "Den danske kvalifikationsramme for livslang læring". Masteren anbefaler at følgende definition anvendes for arbejdet med at formulere FM: "*Kompetencer omfatter brug af viden og færdigheder (personligt, socialt og metodisk), herunder kompetencen til at kunne reflektere over viden og færdigheder*".

Spørgsmålet er hvordan eleverne med udgangspunkt i formålet for faget og ovennævnte definition kan udvikle deres modelleringskompetence i en undervisningssituation?

Ifølge formålet for biologi skal elevernes læring baseres på varierede arbejdsformer som i vidt omfang bygger på deres egne iagttagelser og undersøgelser (UVM, 2014b). Dvs. undervisningen bør i betydelig grad tilrettelægges så elevernes kompetencer udvikles gennem elevernes egne bevidste modelaktiviteter. Dette er i overensstemmelse med læseplanen og vejledningen for FM som fremhæver at eleverne skal kunne finde, kritisk udvælge, anvende, udvikle og vurdere naturfaglige modeller til forklaring af naturfaglige fænomener og problemstillinger. I forbindelse med elevernes arbejde med udvikling af modeller fremhæver FM at eleverne skal kunne udvikle modeller som sammenfatter egne observationer af naturfaglige forhold. Hensigten er at eleverne skal kunne forstå forholdet mellem det fænomen som modellen repræsenterer, og modellen. Fx kan eleverne baseret på feltundersøgelser arbejde med at udvikle modeller af sø-økosystemer i form af små akvarier i klasseværelset. Hermed bliver der også mulighed for at udnytte den synergieffekt der ligger i at arbejde integreret med modelleringskompetencemålet og undersøgelseskompetencemålet.

Denne praksis skal derudover udfoldes på et personligt, socialt og metodisk plan. Omsat til undervisning vil det betyde at elevernes kompetencer skal tage afsæt i og udvikles når de anvender deres viden og færdigheder til at bruge modeller: (a) personligt, fx til at tilegne sig faglige begreber og sammenhænge omkring søens økosystem, (b) socialt, fx til at formidle, udvikle og revidere deres akvariemodeller på gruppe- eller klassebasis, og (c) metodisk, til fx at anvende modeller til at forudsige resultatet af forskellige næringsstofbelastninger på søens økosystem.

Det fremgår af masteren at eleverne skal vise kompetence i konkrete situationer ved at bruge viden og færdigheder til at løse opgaver og reflektere over opgaveløsningen (*UVM, 2013*). Kompetence omfatter altså ikke kun brug af viden og færdigheder til fx metodisk at designe en model af en søs økosystem. Den reflekterende dimension af kompetencebegrebet betyder at eleverne skal tilegne sig kompetencer så de kan anvende et vist omfang af metaviden om modeller og modellering. Hvis vi kigger på sømodellen igen, vil det betyde at eleven ud over at designe modellen også skal være i stand til at reflektere over modelleringsopgaven i den givne kontekst. Det omfatter fx en vurdering af hvilke styrker og begrænsninger deres models egenskaber har i forhold til at forudsige processer i en virkelig sø. Denne form for vurdering er i tråd med FM som fremhæver at eleverne skal kunne vurdere naturfaglige modeller mht.

deres anvendelighed og begrænsninger i forhold til at kunne synliggøre og forklare naturfaglige forhold. Hermed bliver der også mulighed for eleverne for både at arbejde med modellering som *proces* og modeller som *produkt*.

Masteren fremhæver ligeledes at ansvar og selvstændighed er vigtige elementer i kompetencebegrebet, fx i forhold til i hvor høj grad eleven kan tage ansvar for sin egen læring. Man kan derfor argumentere for at elevernes metaviden også bør forholde sig til modellernes betydning for elevernes egen læring. I den sammenhæng vil det være oplagt at bruge elevernes praksis med modeller som en integreret del af den formative evaluering. Fx kunne eleverne aktivt involveres i at forholde sig til hvordan deres egne modeller løbende bliver revideret baseret på ny erfaring og viden. Denne revision af modellerne og elevernes refleksion over denne udvikling kan fx dokumenteres gennem elevernes portefølje. Eleverne kan herigennem erkende at modelleringsaktiviteten er relevant og giver mening på det personlige plan.

Ifølge formålet for faget i skolen skal eleverne opnå indblik i naturfagenes epistemologi. Set i det perspektiv bør modelleringskompetencemålet i FM også inkludere elevernes evner til at kunne reflektere over hvorfor og hvordan modeller bruges generelt i naturvidenskab til fx forklaring, forudsigelse eller vidensgenerering. Eleverne kan herigennem erkende at modeller og modellering har en væsentlig værdi i deres egen kulturs forståelse af omverdenen. Fx kan sømodeller bruges til at forudsige hvordan forskellige typer af naturgenopretningsprojekter vil påvirke søens økosystem. Man kan også inddrage historiske modeller i undervisningen som afspejler forskellige verdensopfattelser.

I forbindelse med modellernes betydning for naturfagenes epistemologi vil det også være oplagt at arbejde med det sociale aspekt i forhold til læring og vidensgenerering. Fx kan eleverne præsentere deres sømodeller for klassen og give hinanden feedback i forhold til hvordan modellen kan forbedres så validiteten af elevbesvarelserne på den aktuelle problemstilling bliver styrket. Denne aktivitet kan både bidrage til elevernes erkendelse af at et fagligt fællesskab kan generere ny viden, samt at elevernes egen viden anerkendes og bruges til at løse en konkret problemstilling. Dette kan som læreproces være stimulerende og meningsgivende. Derudover vil klassens præsentationer, diskussioner og feedback kunne fungere som en efterligning af den proces der løbende foregår i den naturvidenskabelige kultur. En kultur hvor modeller netop kommunikeres, diskuteres og evt. efterfølgende revideres med henblik på forudsigelse eller vidensgenerering.

Det understreges i masteren for udformningen af de konkrete FM at elevernes kompetencer skal udvikles gennem viden, færdigheder *samt* holdninger og værdier i et gensidigt og vekselvirkende samspil. Dvs. at elevernes kompetencer ikke kun skal udvikles gennem viden og færdigheder, men også gennem holdninger og værdier. Det vil nok være for ambitiøst at inddrage et værdi- og holdningsperspektiv i enhver kontekst når eleverne arbejder med modeller og modellering. Som antydet i de ovenstående afsnit er der imidlertid ofte mulighed for at arbejde med elevernes indsigt i modellernes betydning for egen læring og verdensforståelse. Hermed er der mulighed for at eleverne erkender hvordan og hvorfor modeller og modellering har en værdi i forhold til læring samt deres og andres verdensforståelse.

Derudover er det indlysende at forskellige naturfaglige problemstillinger indeholder forskellige potentialer i forhold til at arbejde med holdninger, værdier og stillingtagen. Fx vil det være relevant hvis eleverne arbejder med modeller i forhold til at forudsige resultatet af forskellige naturgenopretningstiltag i en sø. Derimod er elevernes holdninger og værdier mindre relevante at inddrage hvis det primære formål med modellen er at afspejle årstidsvariationer i søen.

FM fremhæver at modelleringskompetencemålet skal kombineres med fagets fagspecifikke færdigheds- og vidensmål. Hermed får eleverne mulighed for at integrere det fagspecifikke indhold med fagets praksis (fx modellering), og dermed kan eleverne udnytte den gensidighed og synergieffekt der findes mellem praksis og den fagspecifikke viden. Fx vil elevernes viden om søens økosystem og færdigheder i brug af måleinstrumenter påvirke praksis i forhold til hvad og hvordan der måles, observeres og tolkes på en akvariemodel af søens økosystem. Samtidig vil elevernes praksis med modellen kunne generere ny viden for eleverne om søens økosystem og modellering som metode.

Sammenhæng mellem kompetence-, færdigheds- og vidensmål

De reviderede Fælles Måls måltyper er baseret på "Den danske kvalifikationsramme for livslang læring" hvor der skelnes mellem viden, færdigheder og kompetencer (UVM, 2010). Formuleringerne i FM afspejler eller uddyber imidlertid ikke forskellen på færdigheds- og kompetencemål.

Men som jeg nævnte ovenfor (i afsnittet "Modelleringskompetencemålet omsat til undervisningspraksis"), er en væsentlig forskel at en kompetence er karakteriseret ved en bevidst og reflekteret handling. Forskellen mellem færdigheder og kompetencer kan derudover også baseres på hvor kompleks den foreliggende opgave er, og i hvor høj grad opgaven stiller krav til elevernes metakognitive evner (Dolin, 2014).
Formuleringerne i FM afspejler imidlertid ikke denne forskel på færdigheds- og kompetencemål. Under kategorien færdighedsmål står fx at eleverne skal vælge modeller efter formål og vurdere modellers anvendelighed og begrænsninger (figur 1). Dette kan næppe betegnes som en færdighed da eleverne i høj grad skal bruge deres metakognitive evner til at vurdere og udvælge modeller baseret på komplekse vurderingskriterier i forhold til modellernes egenskaber og opgavens formål.

FM's misvisende brug af begreber udvasker derved forskellen på færdigheds- og kompetencemål. Konsekvensen er at lærerens arbejde med at skelne mellem de to forskellige typer af mål bliver næsten umulig.

Derudover giver FM ingen anvisninger til hvordan læreren gennem undervisningen kan mediere elevernes læring fra videns- og færdighedsmål til kompetencemål.

Hvis FM i højere grad fremhævede at modelleringskompetencen skulle udvikles gennem elevernes reflekterede praksis med modeller, ville det nok også blive tydeligere for lærerne at det var nødvendigt at arbejde med en mere procesorienteret tilgang til modeller.

Derudover er sammenhængen mellem kompetenceområdernes færdighedsmål og de fagspecifikke færdighedsmål ikke systematisk. Det fremgår fx af en usystematisk brug af verber. Fx beskrives færdighedsmålene under kompetenceområdet modellering med følgende verber: "anvende" og "vælge" (figur 1). Ingen af de nævnte verber optræder imidlertid i de tilhørende fagspecifikke færdighedsmål. Eleven skal fx ifølge færdighedsmålet for naturfaglig modellering "vælge naturfaglige modeller". Hvorimod eleverne ifølge de tilknyttede færdighedsmål for de faglige områder evolution, økosystemer, krop og sundhed samt mikrobiologi skal "forklare naturfaglige forhold vha. modeller" (figur 2).

Færdighedsmål				
Naturfaglig modellering	Evolution	Økosystemer	Krop og sundhed	Mikrobiologi
Eleven kan vælge naturfaglige modeller.	Eleven kan med modeller forklare miljøforandringers påvirkning af arters udvikling.	Eleven kan med modeller af økosystemer forklare energistrømme, herunder med digitale databaser.	Eleven kan med modeller forklare reproduktion og det enkelte menneskes udvikling.	Eleven kan med modeller forklare dna's funktion, herunder med digitale programmer.

Figur 2. *Eksempel fra biologifagets Fælles Mål på manglende overensstemmelse mellem brug af verber i modelleringskompetenceområdets færdighedsmål og de fagspecifikke færdighedsmål der omhandler modeller. Verbet "vælge" anvendes fx ikke i de fagspecifikke færdighedsmål (UVM, 2014b).*

De fire kompetencemål: integrering versus opdeling

Ifølge læseplanen skal undervisningen tilrettelægges med *udgangspunkt* i kompetencemålene og *med hensyntagen* til de fagspecifikke mål. De fire kompetencemål, inklusive modelleringskompetencemålet, har herved fået en meget central lovmæssig betydning for lærerens tilrettelæggelse af undervisningen og elevernes læring i biologi.

Et centralt spørgsmål er om matrixens skarpe opdeling i de fire kompetencemål er hensigtsmæssig da der er et stort overlap mellem de fire kompetencer. Fx kan både modellerings- og undersøgelseskompetencen karakteriseres ved følgende egenskaber: analysere, præcisere, videreudvikle, beskrive og generalisere mellem praksis og teori.

Derudover kan den skarpe opdeling signalere en unødvendig mekanisk tilgang til undervisningen som vil modarbejde den synergieffekt det har at arbejde integreret med flere af kompetencemålene i en og samme undervisningssekvens. Fx vil det være oplagt at eleverne anvender modeller til opstilling af undersøgelseshypoteser og til perspektivering af undersøgelsesdata.

Hvis overlappet mellem de fire kompetencer og synergieffekten skal udnyttes funktionelt, vil det kræve at lærerne er opmærksomme på at flere af kompetencemålene kan bringes i spil som en helhed i undervisningen. Elevernes modelleringskompetencer kan fx bringes i spil når eleverne planlægger, gennemfører, vurderer, kommunikerer og perspektiverer deres egne undersøgelser.

Man kan dog også argumentere for at en opdeling og kategorisering af kompetencebegreberne i FM er nødvendig og meningsfuld for lærerne i deres undervisningspraksis. Fx vil beskrivelsen af de fire kompetencemål hver for sig tydeligt fremhæve kompetencemålenes forskellige karakteristika. Dette kan være en hjælp til læreren når den målstyrede undervisning skal planlægges, gennemføres og evalueres. Derudover kan det være en fordel for eleverne i forhold til at forstå hvilken naturfaglig praksis de arbejder med, og skelne mellem naturfagenes forskellige praksisser.

Som det fremgår af ovenstående, vil det være kontekst- og formålsbestemt hvornår det vil give mening at arbejde integreret eller opdelt med de forskellige kompetencemål.

Progression i de fire kompetencemål

Det fremgår af vejledningen at læreren skal tilstræbe en vis progression i tre af de fire overordnede kompetencemål. Således skal der indlejres en progression fra undersøgelse over modellering til perspektivering. Dette kan sikre en vis sammenhæng mellem kompetencemålene. Det er dog ikke uproblematisk at tilstræbe denne progression i alle undervisningsforløb. Ud fra et motivationsaspekt kan det fx være meningsfyldt at starte med en perspektivering fx med udgangspunkt i en dagsaktuel historie. Det vil også være oplagt at arbejde med modeller af naturfaglige fænomener inden eleverne skal opstille hypoteser for deres undersøgelser af fænomenet som modellen repræsenterer.

De fire kompetencemål og fagets formål

Man kan ligeledes problematisere om denne fokusering på de fire kompetencemål kan risikere at forsimple biologifaget og dermed reducerer mulighederne for at opnå det overordnede formål for faget. Hvis denne forsimpling skal undgås, kræver det at lærerne: (a) har en nuanceret forståelse af de fire kompetencer og (b) løbende forholdr sig til hvordan de fire forskellige kompetencemål bedst kan bidrage til at opfylde formålet for faget.

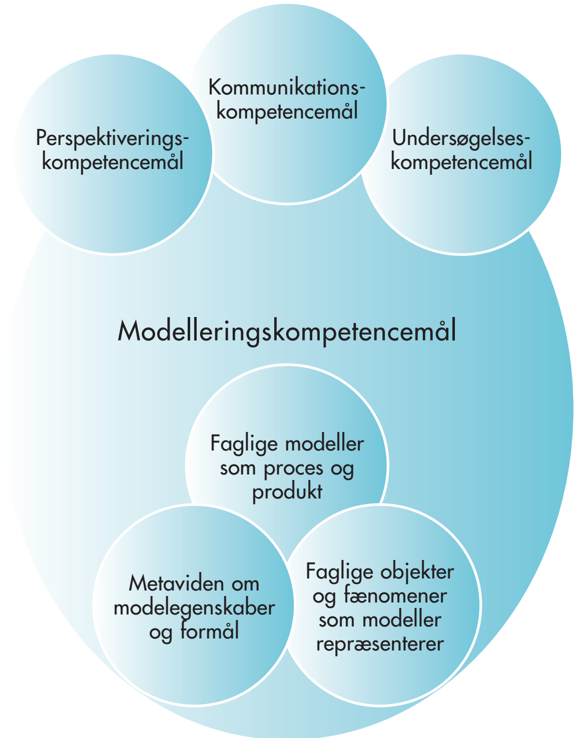
Jeg vil påstå at FM inklusive det understøttende materiale på hjemmesiden kun i begrænset omfang beskriver: (a) de fire overordnede kompetencer og (b) hvordan de forskellige kompetencemål kan bidrage til at opfylde fagets formål. Jeg mener derfor at en uddybelse af sammenhængen mellem formålet og kompetencemålene illustreret med konkrete eksempler vil bidrage væsentligt til lærernes arbejde med at realisere fagets formål gennem kompetencemålene.

Konklusion

Sammenfattende kan man sige at modelleringskompetencemålet i en undervisningskontekst bør inkludere elevernes evner til, sammen med andre eller individuelt, at designe, anvende, sammenligne, udvikle, evaluere og revidere biologifaglige modeller som *produkt* og *proces*. Dertil kommer at modelleringskompetencemålet bør inkludere elevernes evner til at forstå sammenhængene mellem det fænomen som modellen repræsenterer, og modellen.

Modelleringskompetencemålet bør også inkludere elevernes *metaviden* om modellernes karakteregenskaber og formål. Dvs. målet bør inkludere elevernes evner til at forstå og reflektere over modellernes egenskaber og formål i forhold til: (a) kontekstbundne opgaveløsninger, (b) hvordan modeller som en del af de naturvidenskabelige arbejdsmetoder kan bidrage til forudsigelse, idé- og vidensgenerering, (c) hvordan modeller som formidlingsværktøj kan bidrage til vores omverdensforståelse, og (d) hvordan modeller kan bidrage til egen læring og omverdenforståelse.

I overensstemmelse hermed vil en integrering af modelleringskompetencemålet med et eller flere af de andre kompetencemål udnytte den potentielle gensidighed og synergieffekt der ligger i at arbejde integreret med de forskellige kompetencemål. Fx kan modelleringskompetencemålet i en specifik undervisningssekvens inkludere elevernes evne til at anvende faglige modeller til planlægning af undersøgelsesdesign, dataanalyse og formidling. Ovenstående betragtninger er illustreret i figur 3.



Figur 3. *En fortolkning af modelleringskompetencemålet i Fælles Mål præsenteret som et samspil mellem (a) biologifagets faglige modeller som produkt og proces, (b) metaviden om modellernes karakteregenskaber og formål og (c) det fænomen som modellen repræsenterer og modellen. Fortolkningen indebærer at modelleringskompetencemålet integreres med de andre kompetencemål.*

Formålet med revisionen af FM var at formulere målene så enkelt og klart at de blev lettere at anvende som didaktisk planlægningsredskab, og herigennem at understøtte at lærernes undervisning blev mere målstyret. Fælles Måls meget generelle formuleringer, manglende definitioner på centrale begreber, begrænsede detaljeringsgrad, en uklar sammenhæng og manglende tydelighed i fasebeskrivelserne, usystematisk skelnen mellem færdigheder og kompetencer og matrixens skarpe opdeling af kompetencemålene kan imidlertid udgøre en betydelig barriere for at lærerne kan omsætte disse intentioner til praksis. Vejledningen og undervisningseksempler på EMU-hjemmesiden beskriver hvordan eleverne konkret kan arbejde med modeller i biologi. Eksemplerne kan uden tvivl understøtte lærerens arbejde, men de kan ikke stå alene som fortolkningsramme for intentionerne i FM.

Udformningen af FM for biologi inklusive læseplanen og vejledningen indebærer at ansvaret for fortolkningen af kompetencemålene i dag i vid udstrækning er lagt over til den enkelte lærer eller det enkelte lærerteam.

Såfremt modelleringskompetencemålet i FM fortolkes og kan omsættes til praksis, som det er illustreret i figur 3, kan inddragelse af modeller og modellering i undervisningen dog i høj grad bidrage til at opfylde formålet for biologifaget i folkeskolen – og dermed også intentionerne i FM. Men det vil som minimum kræve at lærerne arbejder med et bredt og nuanceret modelleringskompetencebegreb, og at de forstår intentionerne, variationsmulighederne og evalueringskriterierne i de tre faseopdelte målprogressioner i figur 1.

Derudover vil det kræve at lærerne i deres tolkning og undervisningspraksis ikke altid pr. automatik sætter lighedstegn mellem undervisningsforløbets progression og de faseopdelte målprogressioner.

Tak til Seth Chaiklin, Jens Dolin, Lars Sejersgård Jakobsen og Jens Aarby for gode diskussioner og konstruktive kommentarer.

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www.emu.dk. EMU Danmarks læringsportal. En del af Undervisningsministeriets hjemmeside som fx indeholder udvalgte undervisningsforløb og udfordringsopgaver til eleverne.

Engelsk abstract

This paper describes the strengths and weaknesses of the new Simplified Common Objectives with regard to their ability to facilitate the teachers' efforts to implement the modeling-competence-objective in biology classes. It is suggested how the modeling term and the modeling-competence-objective can be interpreted, when models and modeling should be integrated in the teaching in a qualified manner. It is discussed how the content and format of the new Simplified Common Objectives facilitate teachers' efforts to qualify the use of models and modeling in their teaching. Concrete examples are provided with regard to how the modeling-competence-goal can be unpacked and operationalized in order to enable coherence between the overall aim of the biology curriculum, the modeling term and the modeling-competence-objective.

Paper 2.

Nielsen, S.S. (2018). Prospects and Challenges in Teachers' Adoption of a New Modeling Orientated Science Curriculum in Lower Secondary School in Denmark. *ESERA Conference Proceedings Series* 1333-1344.

PROSPECTS AND CHALLENGES IN TEACHERS' ADOPTION OF A NEW MODELING-ORIENTED SCIENCE CURRICULUM IN LOWER SECONDARY SCHOOL IN DENMARK

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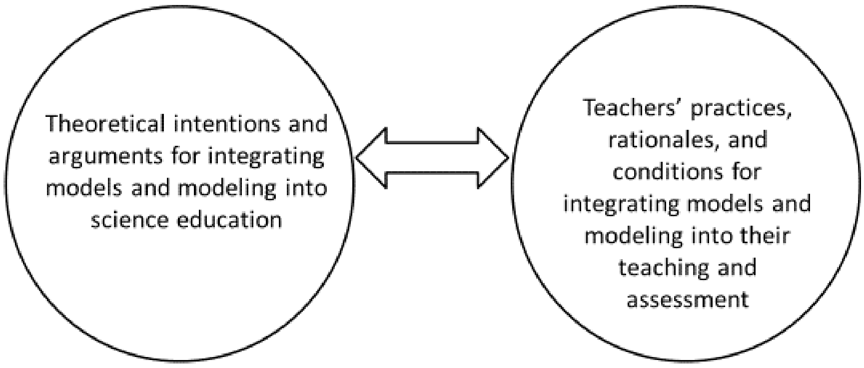
Abstract: A new science curriculum with a significant emphasis on modeling has recently been adopted in Danish compulsory education. The purpose of this paper is to identify the key changes between the new and previous curriculum, and analyze what kind of prospects and challenges this may lead to when teachers adopt this new curriculum. The data sources include audio recordings of three teacher-teams' talk-in-interaction during their instruction planning. In addition, science teachers completed an electronic questionnaire (n=227). Significant changes were identified between the new and previous curriculum in relation to: (i) The characteristics of what and how to address models and modeling in the teaching, (ii) Assessment requirements, (iii) Teaching approaches, (iv) Subject-specific versus interdisciplinary teaching, and (v) The prioritizing of different inquiry practices. The analysis suggests that teachers have a positive attitude towards the modeling emphasis in the new curriculum, and models play an important and valued role as a learning tool. In addition, teachers have a tendency to see models as a product of content knowledge and concepts to be learned. Teachers raised concerns in adopting the new curriculum due to: (i) Lack of time for preparation, teamwork and teaching, (ii) Shortage of clarifications and examples in the curriculum materials, (iii) Shortage of teacher education and in-service training how to adopt modeling in practice, (iv) Overcrowded curriculum and fragmented teaching time with students, and (v) Lack of alignment with a national test and an exam. The findings will have implications for teacher education, professional development and curriculum development.

Keywords: Modeling competence, Science curriculum reform, Teachers' practice.

INTRODUCTION

A new school reform has recently been adopted in Danish compulsory education, commencing in the school year 2015-2016 (Ministry of Education, 2014a). This reform includes changes to the national science curriculum for lower secondary education (grades 7 to 9). One significant change relates to an enhanced focus on models and modeling in teaching and assessment. This study examines the prospects and challenges for teachers in adopting the new modeling-oriented curriculum. The focus is on the tension and gap between theoretical educational intentions and arguments for integrating models and modeling into science education, on the one hand, and teachers' practices, rationales and conditions for integrating models and modeling into their teaching and assessment practice, on the other (Figure 1). In this study, the modeling aspects of the new curriculum and the key purposes of science education represent the theoretical intentions and arguments.

Figure 1. Two perspectives on integrating models and modeling into science education. Illustrated as tensions between theoretical educational intentions and arguments and teachers' practices, rationales, and conditions on integrating models and modeling into their teaching.



The assumption for this study is that the degree of alignment between theoretical intentions and teachers' rationales, practices and conditions significantly affects the prospects and challenges for adopting the new curriculum. This assumption is aligned with former studies showing that science teachers' rationales, conditions, and practices challenge the prospects for adopting the intentions reflected in competence and goal-targeted curricula (e.g. Sølberg, Bundsgaard & Højgaard, 2015). However, as emphasized by Kenn and Osborne (2017), these challenges and prospects are also directly related to the prioritization, volume and descriptions of the content in the curriculum. This also includes how the curriculum elaborates on why and how the content could contribute to accomplishing key purposes of science education (Osborne, 2014).

The Danish school context

In Denmark, science is taught as an integrated subject from grades 1-6 (age 7-13). From grades 7-9 it is taught as three separate subjects: biology, geography, and integrated chemistry/physics. There is no national standard on how to structure science lessons during the school year. However, each science subject is typically distributed equally across the school year with 1-3 lessons (of 45 minutes) per week (Figure 2). This study only considers grades 7-9. Science teachers most frequently teach 6-10 science lessons per week with a range of 2 to more than 17. Most teachers teach two different science subjects.

Figure 2. Number and distribution of science lessons (of 45 minutes) per week by subject and grade in Danish compulsory education.

Subject	Grades 1-6 (age 7-13)	7th grade (age 13-14)	8th grade (age 14-15)	9th grade (age 15-16)
Science & technology	1-3	0	0	0
Biology	0	2	2	1
Geography	0	2	1	1
Physics & chemistry	0	2	2	3

THEORETICAL BACKGROUND

Models and modeling offer prospects for accomplishing some of the key purposes of science education

Models and modeling are central for teaching and learning science and are seen as a core practice in science and scientific literacy (Lehrer & Schauble, 2015). The term 'model' can be perceived as a product of science whereas the term 'scientific modeling' refers to a process or practice used in science that involves: developing models by embodying key aspects of theory and data into a model; evaluating models; revising models to accommodate new theoretical ideas or empirical findings; and using scientific models to predict and explain the world (Schwarz & White, 2005). Since modeling involves repeated cycles of developing, representing and testing knowledge, modeling is an important part of scientific inquiry (Lehrer, Schauble, Lucas, 2008). Lehrer and Schauble (2015) have suggested that science is primarily a 'modeling enterprise'. They have argued for a broad perspective on modeling as a core scientific practice with prospects for incorporating other science practices (investigation, communication, argumentation, questioning, etc.) when constructing, revising, critiquing and contesting models of aspects of the natural world.

Several scholars have pointed to the affordances of modeling in facilitating students' learning of science concepts, scientific reasoning processes and awareness of how science works (Campbell & Oh, 2015; Nicolaou & Constantinou, 2014; Schwarz et al., 2009). These affordances of modeling in facilitating students' learning conform to three of Hodson's (2014) purposes for science education: learning science, learning about science, and doing science.

The above mentioned learning prospects for modeling, is also aligned with the purpose of science education as reflected in the PISA 2015 framework (OECD, 2017). The framework highlights three distinguishable but related elements of knowledge that are required to accomplish science literacy. The first is "content knowledge", corresponding to Hudson's (2014) "learning science". The second, is "procedural knowledge". Finally, the third is "epistemic knowledge". Note that Hudson's (2014) "knowledge about science" is made more specific in the PISA document by splitting it into the two components – procedural knowledge and epistemic knowledge.

In sum, integrating models and modeling as a core scientific teaching practice offers prospects for accomplishing some of the key, internationally-agreed purposes of science education.

A competence-based approach to models and modeling

In Denmark and internationally, there has been a strong educational effort to engage students in scientific practices such that the key purposes of science education shifts from students knowing scientific and epistemic ideas to students developing and using these understandings as tools to make sense of the world (Berland et al., 2016; Ministry of Education, 2014a; OECD, 2017).

In science education, the concept of competence is still the subject of ongoing debate. In this paper, the concept of competence is framed in an educational context and considered to be subject-specific. This framing is inspired by the definition proposed by Busch, Elf & Horst

(2004). In their definition, they describe a subject-specific competence as: a domain-specific insightful readiness to successfully act in a way that meets the challenges of a given situation which contains a particular domain-specific problem (slightly modified by the author during translation to fit English). In other words, a subject-specific competence approach to science education implies that students should apply their scientific knowledge to different situations or tasks related to science-correlated issues.

The strong reference to application of scientific knowledge aligns well with the above mentioned effort to shift the key purposes of science education from students who have scientific content knowledge, procedural knowledge, and epistemic knowledge, to students who apply these different elements of knowledge.

Former approaches to science education focused predominantly on the content knowledge of the models – *the product of science* - without developing an understanding of the processes that led to the knowledge embedded in the model or the purposes, value and utilizations of models in science (Kind & Osborne, 2017; OECD, 2017). In this kind of *product-oriented approach* to modeling, teaching will focus on the use of established models to describe and explain scientific concepts and their relations, while the modeling process leading to this knowledge attainment will play a minor role. In addition, a *product-oriented* teaching approach to models will merely focus on models as representations of already well-established knowledge and how this knowledge is represented in the models. This approach aligns well with what Gouvea & Passmore (2017) define as *models of* something. According to Kind & Osborne (2017), a *product-oriented* approach will mainly provide students with lower-order cognitive challenges of recall, comprehension and application. In addition, if models are solely introduced in the classroom as representations of what is known and not as tools for inquiring, students' prospects for engagement in applied scientific practice will be reduced (Passmore et al. 2014).

In contrast, in a competence-based practice, the starting point for integrating models into teaching should be "what should students be able to do with models – and what kind of knowledge do they need to know to do it?" This kind of teaching entails a *process-oriented* approach to models. In process-oriented teaching, the focus will be on models as tools for dealing with scientific tasks, for example, models' nature and use for predicting, knowledge-generating, problem-solving, discussion and sharing of data. This applied view to models shares features with Gouvea & Passmores' (2017) *models for* teaching approach, with a strong reference to the epistemic functions of models (what they are for). They advocate an approach aimed at facilitating students' development, understanding and valuing of the *processes of science* that led to the knowledge embedded in the models, e.g. a teaching that emphasizes students' engagement with designing and using models as tools for supporting inquiry and exploration. In the same vein, Nicolaou & Constantinou (2014) emphasize the affordance of including students' meta-knowledge on the nature, use and purpose of models, and criteria for evaluating them in competence-based teaching.

In this way, integrating a competence-based approach to models and modeling as a core scientific teaching practice can facilitate the efforts to shift the key purposes of science education away from students knowing scientific and epistemic ideas, to students developing and using these understandings as tools to different situations or tasks related to science-correlated issues.

The way in which these prospects are used, however, depends on the assumption, prioritization and description in the curriculum of how and what kind of knowledge and practice teachers are supposed to integrate into their teaching and assessment.

THE NEW REFORM INCLUDES CHANGES IN THE CURRICULUM'S *HOW* AND *WHAT* TO TEACH AND ASSESS

The new reform includes a significant change to the national science curriculum. In the previous curriculum, each of the three science subjects was taught separately. In addition, there was a strong focus on field and laboratory investigations as the main inquiry practice in science. Furthermore, the knowledge and skills to be taught held a dominant position, and were to a large extent approached as two different aspects of learning (Ministry of Education, 2009). Another major change in relation to the former curriculum is the introduction of a requirement for teachers to integrate the three separate science subjects into six different interdisciplinary units from grades 7 to 9.

Another significant change for all the science subjects involves a statement of what students should learn in terms of four main competences: investigation, modeling, contextualization, and communication (Ministry of Education, 2014a). For each of the four competences, there is a related competence goal and three pairs of related skills and knowledge goals (Figure 3).

Figure 3. **The new science curriculum describes what students should learn in terms of knowledge, skills and competence goals. Here exemplified by modeling for biology (Ministry of Education, 2014b)**

Competence	Competence goal	Skills	Knowledge
Modeling	Student can use and evaluate models in biology	Student can use models to explain scientific phenomena and issues	Student has knowledge about modeling
		Student can select models according to purpose	Student has knowledge about the characteristics of models in science
		Student can evaluate models	Student has knowledge about evaluation criteria for models in science

The competences are intended to play a significant role in school science instruction and assessment in Denmark. This intention is reflected in a legal requirement for teachers to assess students' learning of the competences in their day-to-day assessment, and to use the competences as a starting point for instructional planning (Ministry of Education, 2014a).

Compared to the pre-2014 curriculum, the focus on models and modeling is particularly novel (Ministry of Education, 2009, 2014b). This focus is reflected in the frequency of the term "model" and "modeling" in the curriculum requirements. In the pre-2014 biology curriculum, "model" is mentioned twice and modeling not mentioned, whereas model is mentioned 44 times and modeling 25 times in the new biology curriculum (Ministry of Education, 2009, 2014b). It is not only the frequency of terms that is used differently, however, but also the way in which the role of models is described. In the former curriculum, the description only relates to the nature of models to visualize something abstract; students' practice with models is related to description and explanation, and students' evaluation of a given model is related to its explanatory power (Ministry of Education, 2009). The new curriculum has a more elaborated description. For instance, students' evaluation of a given model is related both to its explanatory and to its representational power. Furthermore, the nature of models is related to their adjustability to fit different purposes, simplification, accessibility, and visualization. In addition, modeling is (but only to some extent) perceived as an inquiry practice. For example, the description of students' use of models is not limited to their explanation of scientific phenomena but also includes a requirement to evaluate models, compare and select between multiple models, and design and revise models (Ministry of Education, 2014b). In sum, the new curriculum contains significant changes to the characteristics of what and how to address models and modeling in teachers' science teaching. The description in the new curriculum (although not very detailed) seems to share many characteristics with a competence-oriented approach to models and modeling.

In addition, from 2017, a new final interdisciplinary oral science exam has been introduced at Grade 9 to test students' learning within the competences (Ministry of Education, 2015). In addition to this exam, students are assessed by external national tests and an additional subject-specific final exam. The additional exam is randomly selected between the three separate science subjects. In contrast to the competence-based exam, the external national tests and the additional exam are individual, digital and composed of multiple-choice questions. In sum, the new curriculum includes changes to the characteristics of what and how to address models and modeling, teaching approaches, new prioritizing and more variation in the use of scientific practices, new interdisciplinary teaching units, and new format and criteria for assessment (Figure 4).

RESEARCH QUESTION

What kind of prospects and challenges do teachers perceive when adopting a new curriculum based on a competence-oriented approach to models and modeling to accomplish key purposes of science education?

METHODS

To answer the RQs, an electronic survey questionnaire with a five-point Likert Scale rating and boxes for additional comments was distributed via email. The survey questions were challenges, prospects and motivations with respect to adopting the new modeling-oriented curriculum in their teaching and assessment practices. With one survey reminder, 227 teachers responded (31.6% response rate). To obtain a more in-depth explanation of the issues raised in the questionnaire, and to elaborate on some of the responses, a more detailed and qualitative study was conducted. The participants in this part of the study were six voluntary science teachers with different teaching experiences (2-20 years), employed at three schools each representing different academic achievement groups of students. The data from this part of the study consist of audio recordings of teachers' talk-in-interaction during their instruction planning of a teaching unit focused on models and modeling. The planning was part of a larger action research project. The researcher took an active part in the planning by raising reflective questions related to the teachers' rationale and practice with respect to models and modeling. To facilitate the talk-in-interaction and teachers' reflection, labels with pre-formulated statements were regularly presented by the researcher during the planning session. The discussions were conducted with one teacher-pair at each school. All audio recordings were transcribed. The preliminary data analysis was guided by the research questions. and focused on two overarching themes: teachers' perceptions of the prospects and challenges for adopting the new modeling-oriented curriculum, and teachers' practices, rationales and conditions with respect to models and modeling.

Figure 4. Curriculum and assessment changes for science education from grades 7 to 9 related to the new school reform.

	Curriculum and assessment intentions before the reform	**Curriculum and assessment intentions after the reform**
Teaching approach	Knowledge and skills dominate what students should learn. Knowledge and skills mainly approached as two different aspects of learning.	Four main competence-statements dominate what students should be able to do.
Inquiry practice	Strong focus on field and laboratory investigations as the main inquiry practice in science.	Modeling added as an inquiry practice in science.
Aspects of practice with models	Models to communicate, describe and explain.	Models to communicate, describe, evaluate, compare, design, revise, and select between multiple models.
Roles of models	Models as representations of established knowledge.	Models as representations of established knowledge and models (but only to some extent) as tools for inquiring.
Nature of models	Visualize, simplify. Models of something.	Visualize, simplify, accessibility, and adjustable. Models for something.
Separate science subjects versus interdisciplinarity	Science taught as three separate subjects.	Six interdisciplinary science units added to the subject-specific teaching.
Assessment format and criteria	Individual, subject-specific, digital, multiple-choice national test and final exam, mainly assessing content knowledge and procedural knowledge related to variable control.	New final group-based, interdisciplinary oral and practical science exam assessing students' competences. Subject-specific national test and a randomly selected individual, subject-specific, digital, multiple-choice final exam.

PRELIMINARY RESULTS

Teachers' practices and rationales for integrating models and modeling into their teaching

Teachers' responses to the questionnaire show that they have a diverse understanding and use of models. This diversity was particularly reflected in the free text boxes, with teachers' examples of physical forms of models used in their teaching. In general, the teachers acknowledged the numerous examples of model types that they used in their teaching. For example, one teacher wrote: "*No* [science] *teaching without models*" and another wrote: *"My daily teaching varies greatly and is inquiry based* [...] *so many different models are used* [...] *it is not possible to avoid the periodic system; we have a new interactive one* [periodic system] *in the passage so that all students can be inspired and be curious*". The need as well as the value of models in teaching was frequently reflected in the teacher-teams' talk-in-interaction during their teaching planning as well, as exemplified by this quotation: "*It* [models] *permeates the way we explain* [scientific] *stuff. In the communication of science you can neither avoid nor do without models.*" In addition, during the teaching planning, the teachers often emphasized and exemplified how students' understanding of models forms part of the reading and understanding of science. In sum, the analysis of the questionnaire, as well as the talk-in-interaction, demonstrated that models were already an integral and valued part of teachers' existing practice, and perceived as a needed and central part of science teaching.

Teachers' precipitation of the affordance of models was closely linked to students' learning of science concepts (i.e. Hudson's *about science).* As reported in the questionnaire, the most common model practice was *"Students' explanations of scientific phenomena",* while more process-oriented practices were used to a lesser extent, i.e. predicting, revising and designing. The least used practice was *"Students' revisions of models".* Although the different teachers used models in a diverse way, the teacher-teams' talk-in-interaction generally reflected a more product-oriented approach to modeling as opposed to a more process-oriented one. This is exemplified by this quote:" *I think the overall purpose* [for using the model] *is that I want them* [the students] *to understand the protein synthesis and you* [the other teacher] *want them to understand the nitrogen cycle*". In sum, most (but not all) teachers had a tendency to see and use models as a product of content knowledge and concepts to be learned. Aspects of meta-knowledge seemed to play a minor role in teachers' practice. However, when addressed in the teaching planning, it was mainly related to the existence of multiple models designed for different purposes or limitations in representing the target. The nature of models was mostly related to simplification and visualization. However, the tentative and progressive nature of models was emphasized when related to specific topics (e.g. evolution and structure of atoms).

Teachers' school-specific conditions

Many of the school-specific conditions affecting how teachers were able to adopt the new curriculum were directly or indirectly related to time. For instance, teachers struggled with engaging students' in more time-consuming practical and process-oriented modeling activities due to limited and fragmented teaching time per class (see Figure 2). In addition, with few teaching lessons per class, teachers found it hard to change the class culture from a more knowledge-based to a more competence-based approach. This point was especially highlighted by teachers who only taught one or two of the science-specific subjects and particularly biology and geography teachers.

Another issue related to time was the relationship between teaching lessons in science and other school subjects. Teachers with few science lessons reported a very restricted time allocated for in-service training, teamwork, preparation, and meetings related to science. Teachers perceived this as a limiting factor for their possibilities of prioritizing and adopting the new curriculum in the day-to-day teaching. Furthermore, teachers found it difficult to find time to develop and share new teaching and assessment approaches. The completed questionnaires showed that less than 30% of the teachers thought they "*had time to meet with science colleagues to develop how to realize the intentions of the new curriculum*."

Support for teachers in terms of how and why to adopt the theoretical intentions of the new curriculum

Another issue raised by teachers was related to how models and modeling are addressed in the curriculum and teaching materials. Teachers described how the following aspects challenge their efforts to adopt the curriculum: lack of clarifications and examples in the curriculum materials; insufficient explanation as to why and how models and modeling can accomplish the key purposes of science education; lack of teaching material and/or the existing material did not fit into teachers' valued teaching approach; a central part of the curriculum format signals a "skill and knowledge check list" compared to requests for a more competence-based approach to the interdisciplinary units described in the curriculum; overcrowded curriculum; and a mismatch between curriculum requests and students' abilities. Teachers particularly called for guidance and support in assessing students' models and modeling progress and achievements.

Lack of alignment between central assessment requests and a competence-based approach to models and modeling

In Denmark, there is a strong tradition of collaborative and practical work that is well suited to a competence-based approach to models (i.e. student sharing, discussing and designing models). Teachers note that this kind of approach was aligned with the interdisciplinary exam. In contrast, the subject-specific multiple-choice national test and the randomly-selected exam is individual and mainly assesses content and "variable control" knowledge. Some teachers expressed how this kind of assessment shifts their teaching towards a more knowledge-based approach to models and modeling, with less time allocated for discussion and practical work. The process of evaluating and revising models was found to be rather time consuming and therefore rarely used.

An overcrowded curriculum means limited time for students to engage in practical and process-oriented modeling activities

A repeated issue raised during teachers' preparation work was a mismatch between teaching time and an overcrowded curriculum. Teachers stated that the introduction of the six interdisciplinary units had increased this mismatch.

Teachers' knowledge and experience of models and modeling

From the time the new curriculum was implemented, and over the next three years, 80% of the teachers who answered the questionnaire said they had participated in less than 20 hours of in-service training related to science. In the same vein, less than 20% of the teachers agreed or highly agreed that they had participated in sufficient in-service training to integrate modeling into their teaching as a competence-based practice. In addition, 15% agreed or highly agreed that they had obtained sufficient knowledge during their teacher training on how to integrate models into their teaching.

DISCUSSION AND CONCLUSIONS

Significant changes were identified between the previous and new curriculum in relation to the characteristics of *what* to address and *how* to address models in the teaching. The pre-2014 curriculum took a knowledge- and product-oriented approach to models. The new curriculum has a more competence- and process-oriented approach. Teaching guided by the new curriculum will mainly focus on students applying and integrating content, procedural and epistemic knowledge to different modeling-oriented tasks, tasks where students are using models as tools for revising ideas, discussion etc. Theoretical intentions in the curriculum do however not in itself transform into changes in the classroom.

Nevertheless, and in line with other countries (Kind & Osborne, 2017), the official curriculum documents in Denmark provide only limited support for teachers in terms of how to adopt the curriculum in practice. The description of the modeling competence is formulated in general, unspecific terms in the curriculum, and not based on a systematic theoretical framework (Nielsen, 2015). In addition, the curriculum includes neither the intentions nor arguments for how modeling as a competence can accomplish the key purposes of science education. Moreover, there is no tradition among Danish government institutions of developing or approving teaching materials targeted at the curriculum or of including guidelines for instruction in the curriculum.

Before modeling can be adopted as a competence-based practice in the classroom, teachers must first interpret and unpack what the different aspects of modeling as a competence-based practice are, based on their own perception of relevance with respect to the key purposes of science education. Secondly, teachers must identify what form of knowledge is required for students to undertake aspects of the modeling practice. In addition, teachers need to identify the potential challenges of the different aspects of the modeling practices. Finally, they must suggest what kind of performance is indicative when assessing students learning in the different aspects of modeling practice. None of these tasks is particularly easy and nor have teachers received much training in how to carry them out (Osborne, 2014). In addition, it is a rather time-consuming teaching preparation process for the teacher to undertake.

In addition, the new reform also includes changes to teaching approaches, new priorities and more variation in the use of scientific practices, new interdisciplinary teaching units, and a new format and criteria for assessment. The introduction of so many major changes is quite a demanding task for Danish science teachers as demonstrated in this study. The analysis suggests that teachers have a positive attitude towards the modeling emphasis in the new curriculum, and models play an important and valued role as a learning tool. Even though the teachers thus really would like to base their teaching on the new curriculum, it remains a tall order. Teachers particularly raised concerns in adopting the new curriculum with regard to: (i) Lack of time for preparation, teamwork and teaching, (ii) Shortage of clarifications and examples in the curriculum materials, (iii) Shortage of teacher education and in-service training how to adopt modeling in practice, (iv) Overcrowded curriculum and fragmented teaching time with students, and (v) Lack of alignment with a national test and an exam.

The assumption of this study is that the degree of alignment between theoretical intentions and arguments for integrating models and modeling into science education, on the one hand, and teachers' practices, rationales and conditions, on the other, significantly affects the prospects of and challenges for teachers in adopting a competence-based modeling teaching practice.

This study indicates a "gap" in this alignment. If we want to narrow this gap, we have to consider the challenges and prospects on each side. This study highlights the following areas for consideration: take advantage of and extend teachers' valued and already well-established modeling practice to make it more process-oriented; ensure better alignment between assessment and teaching approaches, and between the different assessment tests and exams; change the current capacity at school level e.g. to enable science team meetings; rework the existing curriculum to match the number of teaching hours; reconsider how to support teachers in the process from understanding to adopting the curriculum, and reconsider how teacher education and professional development can contribute to this process.

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Paper 3.

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A Competence-Oriented Approach to Models and Modelling in Lower Secondary Science Education: Practices and Rationales Among Danish Teachers

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Abstract
A new science curriculum, with a significant emphasis on modelling, was recently adopted in Danish lower secondary education. The theoretical intentions behind the new curriculum include substantial changes to how teachers should address models and modelling in their practice. The purpose of this study is to analyse the alignment between the intentions and arguments for integrating models and modelling into science education, on the one hand, and teachers' practices and rationales for integrating models and modelling into their teaching practice, on the other. First, this study outlines a theoretical competence-oriented modelling framework. This framework describes what kind of knowledge and practice of models and modelling needs to be integrated into teaching to accomplish a competence-oriented approach in this regard. Second, against the background of this framework, we conducted an empirical study of three teacher-teams' talk about modelling and their practice of integrating models and modelling in their teaching. Our findings suggest that the participating teachers' practices and rationales for integrating models and modelling into their teaching are characterised by a product-oriented approach that is not well aligned with competence-oriented teaching. Finally, we provide ideas for improving the alignment between theoretical intentions and teachers' practice, targeted at science educators and curriculum designers.

Keywords Modelling · Modelling competence · Models · Science curriculum reform · Science teaching

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Introduction

Models play a central role in science, and it could even be argued that the process of modelling is *the* core practice in science (Lehrer and Schauble 2015; Passmore et al. 2014). Models and processes of modelling are also important for science *teaching* because models and modelling can facilitate the learning of science concepts, develop the capacity to engage in scientific reasoning processes and inquiry, and strengthen awareness of how science works (Baek and Schwarz 2015; Gilbert and Justi 2016; Schwarz and White 2005). Nevertheless, we have yet to see a qualified use of models and modelling activities that have had a widespread impact on classroom teaching (Khan 2011; Krell and Krüger 2016; Miller and Kastens 2018; Schwarz et al. 2009). Previous research has documented at least two types of challenge to the integration of models and modelling into science teaching. First, it is difficult for both pre-service and in-service teachers to understand and use models and modelling as well as assess students' learning related to modelling (Crawford and Cullin 2004; Justi and Gilbert 2002a; Miller and Kastens 2018; Windschitl and Thompson 2006). Second, the trend towards modelling taking an increasingly prominent role in science education curricula is often embedded in a wider shift towards *competence-oriented curricula* (Ananiadou and Claro 2009; Crujeiras and Jiménez-Aleixandre 2013)—e.g. in Denmark, where modelling *competence* is now one of four crosscutting competence goals for all science subjects in Danish primary and lower secondary school (Ministry of Education 2014a). The challenge here is that modelling competence is described in so general terms in the curriculum (Nielsen2015) that teachers have almost no guidance as to how to make modelling competence *operational* for teaching and assessment—a challenge that seems to be a general trend in the shift towards a competence-oriented approach (Dolin, Nielsen, and Tidemand 2017; Nielsen, Tidemand, and Dolin 2018).

The study reported here investigated how science teachers talk about how they navigate a competence-oriented approach to modelling in their practice. Specifically, the paper presents an empirical study of Danish teachers' talk in groups and with the interviewer about their practices and rationales when integrating models and modelling into their teaching. This empirical study was conducted against the backdrop of an operational framework for modelling competence that we outline below.

Background

The curricula in many countries, in general, and the Danish science curriculum, in particular, have emphasised models and modelling (Campbell and Oh 2015; Ministry of Education 2014a; NRC 2012). Compared with the pre-2014 curriculum, the current curriculum requires teachers to substantially change how they address models and modelling in their teaching. Most importantly, there is an international trend in education aimed at changing the key learning goals from students acquiring knowledge to students being able to use this knowledge (Ananiadou and Claro 2009; Crujeiras and Jiménez-Aleixandre 2013). Indeed, many curricula have changed from mainly approaching models as *products* of knowledge that students have to learn about to a *competence-oriented approach*.

This paper is concerned with science teachers' talk about their modelling practices. As such, the paper is intended to be relevant to all international contexts in which modelling is part of a science curriculum. But as all empirical studies, the study reported on here happened in a specific national context—that of the Danish science curriculum. Therefore, this section also introduces some of the salient features of that curriculum.

In order for modelling to be adopted as a competence-oriented practice in the classroom, teachers must first interpret what the different aspects of such modelling are—i.e. they must make the competence goal operational (Nielsen et al. 2018). As argued at length elsewhere (Nielsen 2015), the Danish curriculum provides only minimal support for teachers to make "modelling competence"—as a crosscutting learning goal—operational. Indeed, the terms in which the construct of modelling competence are formulated are too general in curriculum documents and not based on a systematic theoretical framework. There is no tradition in Denmark of developing or approving teaching materials targeted at the curriculum or of including comprehensive guidelines for teaching in the curriculum. Similarly, modelling is not explicitly addressed in Danish teacher education (Ministry of Education 2015).

The introduction of competence-based curricula is being used as part of strategic planning for educational change across Scandinavia, and in many European countries (Rasmussen 2013). In science education, the concept of competence is still a topic of ongoing debate (Ropohl et al. 2018; Rönnebeck et al. 2018). In this paper, we will define a competence as an *insightful* readiness to successfully *act* in a way that meets the challenges of a given *situation* containing a particular (subject-specific) problem (cf. Busch et al. 2004). While the concept of competence is not clearly defined in the Danish curriculum (Nielsen 2015), the above-mentioned general definition has been used as a basis for discussing the concept of competence in the context of science education in Denmark, and will later serve as the foundation of our operational framework for modelling competence (see next section). The key point to note is that a competence harbours an *action* component—i.e. a competent person is able to *act in a specific way in a situation* (e.g. able to solve a problem)—rather than just relying on passive knowledge (cf. Ropohl et al. 2018). According to Nielsen and Gottschau (2005), an action in competence-oriented teaching is characterised as being reflective and conscious, and the action should be purposeful and motivated, while at the same time directed at solving a specific problem.

In the next section, we will elaborate on how one might understand modelling *competence*. For the moment, it should be noted that the term "model" can be perceived as a product of science whereas the term "scientific modelling" refers to a practice or process used in science that involves developing models by embodying key aspects of theory and data in a model, evaluating models, revising models to accommodate new theoretical ideas or empirical findings, and using scientific models to predict and explain the world (Baek and Schwarz 2015; Schwarz and White 2005). Baek and Schwarz (2015) emphasise the prospect of engaging students in scientific modelling to facilitate their learning in terms of the following: (a) advancing content knowledge by making invisible processes, mechanisms, and components visible; (b) increasing their understanding of the way that science functions through sharing, evaluating, and revising models; and (c) encouraging students to develop their epistemological thinking by allowing them to attend to the roles of empirical evidence when constructing and revising models. Translating scientific modelling into science classrooms is not, however, a straightforward process (Svoboda and Passmore 2013).

Previous research has documented that it is a demanding task for teachers to change their existing practice and change the way they perceive school science in the shift towards a competence-oriented curriculum (Crujeiras and Jiménez-Aleixandre 2013; Nielsen and Dolin 2016; Sølberg et al. 2015). Lehrer and Schauble (2015) argue that the lack of coherence between curriculum intentions and teachers' practices is partly down to the fact that teachers tend to interpret and assimilate new curriculum requirements into their current familiar schemes. According to Windschitl et al. (2008), the enactment of modelling in classrooms is highly influenced by the way teachers understand scientific inquiry—namely as a self-contained procedure, only nominally linked to content knowledge, and represented by *the universal* scientific method. As in other countries, Denmark has a tradition of prioritising students' learning of *content* knowledge, separating out skills and content knowledge, and merely perceiving the process of science and students' scientific thinking as a matter of laboratory and field work (Ministry of Education 2009). In this light, it must be a daunting task for Danish teachers to change their practice to align with the competence-oriented intentions of modelling in the new curriculum.

Modelling is a diverse and complex process (Justi and Gilbert 2002a; Schwarz et al. 2009), and research suggests that experience and routine are needed to incorporate a qualified application of modelling into teaching (Krell and Krüger 2016; Schwarz and Gwekwerere 2007). Teachers' understanding of models and what modelling as a process entails is crucial to what and how these concepts from the curriculum are adopted into their teaching, and a superficial understanding may restrict students' learning possibilities (Gilbert and Justi 2016; Justi and van Driel 2005; Schwarz and White 2005; Van Driel and Verloop 1999; Vo et al. 2015). Previous studies have reported that different teachers hold rather different ideas about models and modelling in science and enact the use of models quite differently (Khan 2011; Krell and Krüger 2016; Van Driel and Verloop 1999, 2002; Vo et al. 2015); however, some of the challenges in enacting a new modelling-oriented curriculum relate to teachers' limited and often inconsistent knowledge of models and modelling in science (Justi and Gilbert 2002a, 2002b, 2003; Krell and Krüger 2016; Van Driel and Verloop 1999). In particular, teachers' acknowledgement and enactment of the epistemological aspects of models and modelling (Miller and Kastens 2018; Vo et al. 2015; Windschitl et al. 2008) as well as teachers' prioritising of teaching activities that engage students in the process of modelling seem to play a minor role compared with teachers' prioritising of the content knowledge of the models (Campbell et al. 2015; Justi and Gilbert 2002b; Miller and Kastens 2018).

Gouvea and Passmore (2017) argued that a focus on the epistemic functions of models—e.g. having students design and use models as inquiry and exploration tools—may be beneficial for students' development, understanding and valuing of the processes of science. This kind of teaching entails a *process-oriented approach* to models in which the focus is on models as tools for dealing with scientific tasks and issues, for example, models' nature and use in predicting, problem-solving, discussing and sharing of data. In contrast to the process-oriented approach stands a more traditional product-oriented approach that we know will mainly provide students with lower-order cognitive challenges of recall, comprehension and application (Kind and Osborne 2017). Unfortunately, previous studies have documented that the process-oriented approach is rarely adopted wholeheartedly in teaching practice—for example Khan (2011) and Krell and Krüger (2016) found that when students are engaged in the practice of modelling (e.g. designing models), it is often mainly to illustrate or explain a phenomenon or process rather than to compare, evaluate or revise models. To summarise, previous studies of teachers' understanding, appraisal and ways of enacting models and modelling indicate that there is often a gap between, on the one hand, the political intentions and theory of modelling competence and teachers' practices of integrating models and modelling into their teaching, on the other. Consequently, our research questions behind this study were the following:

1. What characterises science teachers' practices and rationales for integrating models and modelling into their teaching practice?

2. How are science teachers' practices and rationales for integrating models and modelling into their teaching practice aligned with a competence-oriented teaching approach to models and modelling?

The Outline of a Framework for Modelling Competence

In this section, we will outline a competence-oriented modelling framework. The aim of this study is not to construct a new framework or put forward an existing one. The aim is to outline a framework describing what kind of knowledge and practice of models and modelling need to be integrated into teaching if modelling competence is to be operationalised at the classroom level and at the same time be in alignment with the descriptions in the curriculum.

Although work has been done to define modelling in science education, the term is still conceptually ill-defined and scholars have called for clarification (Campbell et al. 2015; Gilbert and Justi 2016; Nicolaou and Constantinou 2014). In this light, the framework outline serves several purposes in our study. First, the framework will be used to make our theoretical position transparent. Second, the framework will be used as a backdrop for our empirical analysis of teachers' practice and rationale for integrating models and modelling into their teaching. Finally, the framework will be used to discuss the implications of how to enhance teachers' possibilities of teaching for modelling competence.

Development of the framework took account of the intentions (what and how to teach) and their justification from two sources: international science education research and the Danish curriculum. In science education research, some efforts have been made to describe modelling as a competence (Grünkorn et al. 2014; Krüger et al. 2017; Nicolaou and Constantinou 2014; Papaevripidou, Nicolaou and Constantinou 2014). In both the Danish curriculum and science education research, we find two dimensions that should be included in a framework for a competence-oriented approach to models and modelling. On the one hand, a dimension that we can call *modelling practices*, which provides an action component and is therefore the core of a *competence*-oriented approach to models and modelling and, on the other, a dimension that we can call *meta-knowledge about models*. Just as efforts have been made in the past to define the concept of modelling as a competence, there have also previously been efforts to describe how to approach modelling as an epistemic practice (Campbell and Oh 2015; Gouvea and Passmore 2017; Lehrer and Schauble 2015), and an inquiry practice in science education (Cullin and Crawford 2002; Passmore et al. 2009; Schwarz et al. 2009; Schwarz and White 2005; Windschitl and Thompson 2006). The descriptions of modelling as a practice share similarities with previous efforts to describe modelling as a competence with regard to taking both meta-knowledge as well as different aspects of modelling practices into account. In addition, other scholars have included modelling references as a practice (e.g. Schwarz and White 2005) in their review of research into modelling competence (Nicolaou and Constantinou 2014).

As above-mentioned other scholars equate the concept of modelling as a competence with modelling as a practice and the description in former research of the two modelling concepts shares many similarities. For this reason, we used scholars' descriptions of the practice of modelling to inform the construct of the framework together with the above-mentioned efforts to describe modelling as a competence. In addition to the dimensions *modelling practices* and *meta-knowledge about models*, we include a third dimension related to *subject-specific knowledge* (we will justify this below) in our framework. The framework thus consists of three dimensions, and these are, in turn, operationalised through a number of aspects (see Fig. 1).

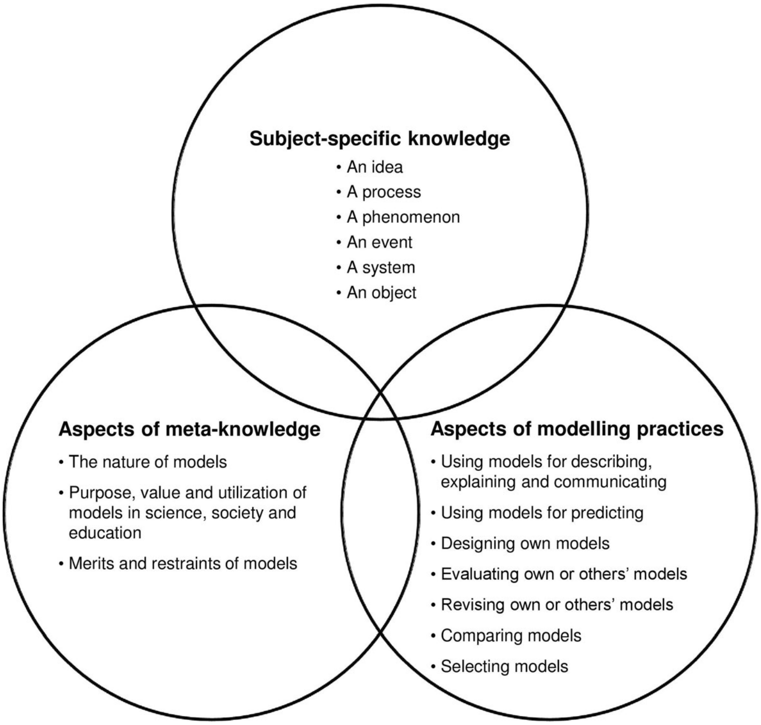

Fig. 1 The modelling competence framework consist of three main elements: *subject-specific knowledge* represented *in models*, *meta-knowledge* about *models and modelling*, and *modelling practices*. The areas with overlapping circles illustrate how the different elements could be integrated together

The dimension of *modelling practices* consists of nine aspects that we have found across the science education research literature and in the Danish curriculum (they are, of course, termed differently in the individual sources): (i) *describing*, (ii) *explaining* and (iii) *predicting* (Grünkorn et al. 2014; Nicolaou and Constantinou 2014; Schwarz et al. 2009; Van Driel and Verloop 1999), (iv) *communicating* targeted at a specific audience (Lehrer and Schauble 2015; Oh and Oh 2011), (v) *designing* (Crawford and Cullin 2004; Ministry of Education 2014b; Papaevripidou, Nicolaou and Constantinou 2014; Passmore et al. 2009; Schwarz et al. 2009), (vi) *evaluating* and (vii) *revising* (Grünkorn et al. 2014; Miller and Kastens 2018; Ministry of Education 2014b; Papaevripidou, Nicolaou and Constantinou 2014; Passmore et al. 2009; Schwarz et al. 2009), (viii) *comparing* (Gilbert 2004; Grünkorn et al. 2014; Ministry of Education 2014b; Papaevripidou, Nicolaou and Constantinou 2014; Schwarz et al. 2009), and (ix) *selecting* (Campbell and Oh 2015; Ministry of Education 2014b). The first four aspects of modelling practices relate to the functional roles of models while the last five relate to the application of these functions. Following Krell and Krüger (2016), we separate the functional roles into *descriptive* roles (describing, communicating, and explaining) and a *predictive* role. To highlight the difference between the descriptive and predictive roles we merge the modelling aspects *describing*, *communicating* and *explaining* and thereby reduce our nine aspects of modelling practices to seven. Our seven suggested aspects are described in more detail in Table 1.

Table 1 Descriptions of the suggested aspects of modelling practices to be included when constructing the modelling competence framework

Aspects of modelling practices	Description
Descriptive use of models	Using models descriptively as a means of describing, explaining or communicating an idea or a phenomenon.
Predictive use of models	Using models predictively as tools for inquiry, problem-solving, sensemaking and/or as hypothetical entities representing different ideas of the referent.
Design own models targeted at a specific purpose	Students design models based on their own ideas, prior evidence and/or theories. The purpose could be related to a model's role in describing, communicating, explaining and/or predicting.
Evaluate own or others' models related to the usefulness decided by the purpose	Students evaluate models based on a model's power of representation, explanation and/or prediction related to a specific question, problem or purpose. Evaluation could be based on students' empirical testing and validation of models or how a model fits with other established models or types of knowledge.
Revise own or others' models to improve their affordance related to the usefulness decided by the purpose	Students revise own or others' models. The revision could change the communicative, representative, descriptive, explanatory, and/or predictive power of the model. Revision could be based on additional evidence, new findings, students' advanced sensemaking or new theoretical aspects of the target.
Compare models related to the usefulness decided by the purpose	Students compare and evaluate multiple models representing the same referent to fit different purposes. The criteria for evaluation could be models' ability to represent, describe, communicate, explain and/or predict.
Select models for a specific purpose	Selecting an appropriate model to solve a specific task or problem based on ability and relevance related to a model's representative, descriptive, explanatory and/or predictive power.

The dimension of *meta-knowledge about models and modelling* consists of three aspects that we have found across the science education research literature and the Danish curriculum (again, they are termed differently in the individual sources): (i) the *nature of models* (e.g. Krüger et al. 2017; Ministry of Education 2014b), (ii) the *utilisation, value and purposes of models*, including the major steps in the process of modelling (e.g. Nicolaou and Constantinou 2014; Schwarz and White 2005), the role of models in science and society (e.g. Lehrer and Schauble 2015; Miller and Kastens 2018; Valk et al. 2007; Windschitl and Thompson 2006), the role of models in educational contexts related to students' sensemaking (Schwarz et al. 2009) and as teaching tools (Papaevripidou et al. 2014), as well as the knowledge with regard to models' adaptability to fit different purposes (Ministry of Education 2014b); and (iii) *models' merits and limitations* (Gilbert 2004; Ministry of Education 2014b; Schwarz and White 2005; Valk et al. 2007), including criteria for evaluating models (Schwarz et al. 2009; Schwarz and White 2005; Ministry of Education 2014b) (see Fig. 1).

We also include a dimension concerning *subject-specific knowledge* because part of being competent involves the ability to apply knowledge (Crujeiras and Jiménez-Aleixandre 2013), and this knowledge must be subject-specific since modelling in science entails representing something from the natural world and this, in turn, requires us to know something about the part of the natural world that is being represented (Lehrer and Schauble 2015). The inclusion of a subject-specific knowledge element is also in line with education documents that state that, in the absence of reasoning with and about disciplinary core ideas to make sense of the world or solve a specific task, students' engagement in modelling is not really an epistemic practice of science (NRC 2012).

In addition, subject-specific knowledge still holds a dominant position in the Danish curriculum and the exam (Nielsen 2018), as well as in teachers' existing practice and the way they perceive school science (Campbell et al. 2015; Schwarz et al. 2009). The addition of a subject-specific knowledge element thus has the potential to make the framework more manageable and meaningful for teachers in contrast to a framework that solely approaches modelling as a practice detached from the subject-specific knowledge represented in the model. Addressing models and modelling as illustrated in our framework in Fig. 1 would not only be in line with a competence-oriented approach to models and modelling, as suggested by educational research, but would also enrich the Danish curriculum. In addition, the construction of the three main elements in our framework would align with Hodson's (2014) three purposes for science education (i.e. learning science, learning about science, and doing science).

Research Design and Methods

This paper is part of a wider study that examines the prospects and challenges for science teachers in adopting a new modelling-oriented curriculum in Denmark. Here, we report on six participating teachers' reflections on their rationale and practice related to their existing and forthcoming teaching with models and modelling. The first criterion for allocating participants was purposely related to the research questions. To inform the research questions, the participants needed to have existing teaching experience and to have scheduled forthcoming teaching in lower secondary science education. Between them, the participants also needed to cover all three science disciplines (biology, geography, physics/chemistry). The second criterion for allocating teachers was related to the methods applied in our study that require teachers with a willingness to and the possibility of participating along with a colleague employed at the same school. We examined the research question through the use of explorative semi-structured interviews (Kvale 2006). We used an explorative and qualitative interview format to capture a broad description of teachers' experiences and meanings from their own perspective. We used a "teacher in pair set-up" for the interviews to facilitate a reflective and generative dialogue fostered by the teachers' different experiences and perspectives (cf. Bryman 2012). We assumed that the pair sessions could yield richer information than an individual discussion between the researcher and a teacher. Moreover, similar to a qualitative focus interview, the pair set-up is suited to exploring and giving importance to teachers' shared views and understandings (Kvale 2006). As mentioned above, a pair comprised teachers employed at the same school. This set-up enabled us to carry out the interviews in the teachers' classroom or working space in order to be on the teachers' home ground and to minimise their workload in participating in the project. Easy access to teaching materials and student-generated products further facilitated our efforts to direct the interviews towards the teachers' concrete classroom experiences.

The aim of this qualitative part of the wider study was to gain an in-depth and nuanced description and understanding of teacher practice and rationales related to their teaching. In this light, we prioritised a small sample size ($n = 6$) over a larger sample. The small sample size ensured that we had sufficient time in which to analyse the interviews and build a convincing analytical picture of teachers' practice and rationales based on richness, nuances and complexity rather than generalisability. While we had no intention of ensuring generalisability through the teacher allocation process, we did consider teaching experience (years, specific teaching subjects and number thereof, education background, different school settings) in the process to ensure our participants reflected a range in this regard.

The result of this allocation process was six teachers who were employed at three schools, each representing student groups at different academic levels, located in urban and suburban areas of the Capital Region of Denmark. We have denoted each teacher with an individual code in the form of a letter (A, B, C, etc.). In addition, the teachers are identified by school, by a number (1 to 3). The reference 1A thus denotes teacher "A" from school 1. The participating teachers had very different teaching experiences (from two to over 20 years). The teachers taught different numbers of science subjects in lower secondary school (1–3 subjects). All teachers taught physics/chemistry, all except one (E3) taught biology, and three taught geography as well (A2, B2, C1). All the teachers had a teaching degree from teacher training involving courses in general education as well as science education. Two of the teachers (A2 & C1) also had a Master's degree in science (in Denmark, primary and lower secondary school teachers normally have a Bachelor's degree). In the pre-2014 curriculum, models were solely related to description and explanation, and the nature of models only related to visualising something abstract; the term modelling was not mentioned (Nielsen 2018). While all the participants had experience of using models as described in the former curriculum, three of the teachers (A2, B2 and E3) who had participated in a specific two-day in-service course dealing with models had expanded their teaching beyond the former curriculum descriptions by trying out some of the teaching activities from the course. The course was designed by a government institution before the curriculum revision, and models were treated as one of four different approaches to inquiry methods in science education. The course mainly dealt with different modes of models, the nature of models, evaluation and/or comparing of models with respect to their limits and affordance in explaining scientific phenomena, and drawing of cycle-models based on students' pre-understanding of a phenomenon (Danish Evaluation Institute 2011). In this study, an experienced teacher is defined as a person with more than 20 years of teaching experience in science and who participated in the above-mentioned course before joining our research project (i.e. A2 and B2). The study was initiated in the same teaching year as a new school reform, a new curriculum and new working conditions were introduced into Danish lower secondary schools (increasing the teaching load and providing less time for preparation). In this light, it was a challenge to find science teachers who had the time and willingness to participate in our study. The sampling was, thus, first and foremost done on a "convenience" basis (Onwuegbuzie and Collins 2007) using our existing network. But in order to coherently answer the research question from the perspective of all science disciplines in our context, it was important for us that the teachers, as a group, represented all science disciplines. Consequently, two teachers (D1, F3) were former students of the first author and both authors knew two of the other teachers from a former research project (A2, B2). The final two teachers were colleagues of the other participants (C1, E3). All participating teachers were volunteers. While there was no accredited research ethics committee involved in the process of informed consent all the participants were informed about the purpose and procedures of the study, the time range, anonymity, and their right to withdraw at any time. In addition, all teachers were promised confidentiality in relation to the school's management so that possible information or results would have no negative impact on them.

We designed the interviews as reflection sessions. The first author conducted the three reflection sessions in Danish with the three teacher-pairs. The sessions ran from 145 to 200 minutes. The interviewer took an active part in the reflection session by raising questions related to the teachers' practice and rationale with respect to models and modelling in their teaching. Furthermore, the interviewer encouraged the teachers to reflect on the prospects for adjusting their existing practice and, if so, why and how. To facilitate the discussion and teachers' reflection, the interviewer placed a range of labels with pre-formulated statements on a table and these were regularly picked up by the teachers or the first author during the sessions. While all statements were picked up during the session, the order of the statements was not predetermined and often the teachers' response would give rise to discussion of a new statement. The statements were framed by science education research and education policy document suggestions on how and why to address models and engage students in different kinds of modelling practices in their teaching. In so doing, we aimed to explore the alignment between theoretical educational intentions and arguments for integrating models and modelling into science education, on the one hand, and teachers' practice, on the other. Some of the statements reflected a more general approach to teachers' rationale for integrating models and modelling into their teaching, for instance, "Use of models holds prospects for improving science education". Other statements directly mirrored how models and modelling could contribute to accomplishing the specific purposes of science education. The formulation of these statements was guided by three of Hodson's (2014) suggested purposes for science education. For example, learning science: "Students use models to explain a certain phenomenon", learning about science: "Students reflect on when it makes sense to create a model", and doing science: "Models can facilitate students' abilities to work scientifically". In addition, the interviewer frequently drew attention to a paraphrasing of the overall purposes for lower secondary science education in Denmark. A range of statements was also related to different aspects of modelling practices. For example, "Students use models for predicting how a certain phenomenon may develop (e.g. over time or in a different context)" or "Students evaluate limitations and scopes of certain models related to purpose" and "Students create models based on their own inquiries" (see Appendix for further examples). The teachers were asked to elaborate on how the statements reflected the use and function of models and modelling in their current teaching. In addition, the teachers designed a poster that was placed on the table during the session and intended to illustrate their ranking of the statements with regard to frequency of use in their current teaching. During the session, both teachers and the interviewer added comments or additional statements to the poster. Inspired by timeline interviews (Adriansen 2012), the intention was to encourage ownership of the process and enable an atmosphere of trust by using the poster as an artefact that would make the session a collaborative process based on the teachers' experiences and, at the same time, make the data generation visible to all. In this way, the interviews attempted to explore the significance of the teachers' own experiences and to appreciate the world from the teachers' perspective. The poster also acted as a "collective memory", easy to return to for verification of the researchers' interpretations of teachers' utterances or for clarification purposes during the session.

Our data set consists of 8.5 hours of audio recordings from the three reflection sessions, and the three posters produced during those sessions. All audio recordings from the sessions were transcribed, listened to again and adjusted against the transcripts. The posters were used to support this process. The recorded talk was analysed using an inductive thematic analysis (Braun and Clarke 2006) with the support of the NVivo software. This open and data-driven approach seems suitable for exploring teachers' experiences and reflections from their perceptions rather than from a pre-existing coding frame. The latter could restrict the analytical lens and lead to a less rich description. In order to have a transparent, robust, and systematic analysis process, we followed Braun and Clarke's (2006) six-phased analytical tool for thematic analysis. The aim of the analysis was to find crosscutting, consistent and prominent themes that emerged from the teachers' talk.

First, the transcripts were re-read several times together with the posters to become familiarised with the data. During the reading, ideas for coding and interesting features in the data were noted. Examples of interesting features were the wide differences in how the different participating teachers approached multiple models. In order to structure the analysis, each teachers' talk was first divided into sequences of turns depending on which of the nine modelling practices (i.e. describing, explaining, communication, comparing, selecting, revising, designing, evaluation, predicting) the sequence addressed. *Second*, the author conducting the analysis identified initial codes in each of the text sequences relevant to each modelling practice and, finally, all text sequences were collated together with each code. During this process, the analyst listened to selected sequences in the audio recordings again to clarify meaning (e.g. in Danish raising/falling intonation signalling the difference between statements and questions and intonation might indicate the attitudes and emotions of the utterer). *Third*, the analyst revisited the initial codes to look for themes. Through several iterative steps, the analyst interpreted and collated these initial codes into candidate main themes and different levels of sub-themes within them. During this process, 38 initial candidate main themes were identified and these were collated by means of tables and mind maps. A short description of each main candidate theme and sub-theme was formulated. This process was done by the first author. Finally, the second author matched the initial codes to the corresponding candidate theme descriptions. No disagreements were found. While there was no attempt at measuring inter-rater reliability, the lack of disagreement at this stage does strengthen the validity of the crucial step in thematic analysis of identifying the themes that emerge from the initial coding. *Fourth*, both authors reviewed the main candidate themes and their sub-themes. In this process, themes were refined, expanded, reduced, combined, moved or rejected. The purpose of reviewing was to improve coherence within each theme, minimise overlap between themes and ensure that there was enough data to support the themes. After several iterative steps, this process ended up with a total of two overarching main themes. The final steps in this process were done by both researchers. *Fifth*, a writing process in which all the candidate main theme descriptions were collated led to our identification of the essence of each of the two overarching main themes. *Sixth*, an initial report in Danish with illustrative quotations from the transcripts was written. This report served as the basis for the results section in this paper. To stay as close to data as possible the translation of the quotations was done as the final step when writing up the results section.

Results

This section presents the results of the thematic analysis of teachers' talk during the reflection sessions related to their existing and forthcoming teaching. The section is focused so as to explicitly elucidate the first research question (What characterises science teachers' practices and rationales for integrating models and modelling into their teaching practice?). The results will *inter alia* provide the background for the elucidation of the second research question (How are science teachers' practices and rationales for integrating models and modelling into their teaching practice aligned with a competence-oriented teaching approach to models and modelling?), which will be the explicit focus in the Discussion section below. In the presentations of the verbatim data, each teacher is given an individual code in the form of a letter. In addition, the teachers are identified by school by a number.

The Characteristics of Teachers' Rationales and Practices for Integrating Models and Modelling into Their Teaching

In the most general sense, our analysis suggests that the participating teachers' rationales and practices for integrating models and modelling into their teaching practice are characterised by a product-oriented approach. This product-oriented approach manifested itself in two distinct overarching themes: (a) the teachers primarily justified the use of models and modelling in their teaching by referring to models as key teaching and learning *artefacts* that facilitate students' learning of core subject-specific content knowledge (hereafter referred to as content knowledge); and (b) the talk revealed an understanding and use of models among the teachers by which models and modelling were treated as the *product* of a scientific process rather than *part* of a scientific process. In the next section, we will describe how the first overarching theme manifested itself in several different ways.

Models as Means to Facilitate Learning of Content Knowledge

The first primary theme that emerged from the analysis of the teachers' talk relates to the way the teachers justified using, or working with, models in their teaching. More concretely, the archetypal justification of using, or working with, models hinged on the notion that models can be constructive in facilitating students' learning of content knowledge. In other words, the intention to have students develop their understanding of content knowledge dictated whether and how models were enacted in the teaching. This theme manifested itself in several different ways.

First, the teachers frequently asserted that it was valuable to include models in teaching *because* models facilitate an explanation and communication of content knowledge. In the words of one teacher: "The inclusion of models permeates the way we explain [scientific] stuff. In the communication of science, you can neither avoid nor do without models" (B2). Another teacher explained how she would typically use models when students ask for help to understand content knowledge: "You will instantly throw yourself into drawings and models" (A2). Indeed, all teachers stated that the main purpose of using models was to facilitate students' learning of content knowledge. For example, one teacher stated: "I think the overall purpose [for using the model] is that I want them [the students] to understand the protein synthesis and you [the other teacher] want them to understand the nitrogen cycle" (D1). In the words of another teacher: "It is one thing for the students to understand and be able to use the model…they might even forget the model, but they grasp the core content point and I guess that's what we really want" (A2). Furthermore, the teachers generally justified the inclusion of models in their teaching by referring to the fact that models can help them to connect their teaching to issues related to science content (e.g. fertiliser in agriculture) in the "real" world. Likewise, the teachers emphasised that students' content knowledge can be developed by comparing elements and processes in models with the "real" world—as illustrated in the following statement: "The whole point in using models is to make connections between the model and reality […] students' should understand the reality by means of models [...] that's actually the intention…or at least one intention" (B2). In this way, models seem to be used purposely as mediating artefacts to facilitate students' understanding of science content knowledge.

In general, the teachers explicitly talked about models as artefacts for recalling and remembering content knowledge—as can be seen in this exchange between two teachers: "In this way the kinaesthetic model functions as a "memory hook" for the students" (A2) "[…] yes, they will never forget how a heat exchanger works" (B2). In addition, teachers' narratives highlighted how models were used as motivating artefacts for understanding content knowledge: "Models can facilitate students' understanding... and in this way also facilitate motivation, and thereby improve science teaching" (B2). Furthermore, models were talked about as artefacts for evaluating content knowledge: "I can use the model to understand where the child maybe doesn't understand something…and then I can inquire into…what do you see here? And what do you understand here? How do you read this? What do you think that arrow is there for?" (A2). In the words of another teacher: "Models could be a tool to identify if the students understand the content we discussed" (E3). In other words, teachers' justification for using, and working, with models hinged on their central role in communicating, explaining, evaluating, and facilitating students' learning of different aspects of content knowledge.

Second, the teachers' rationales for using models in their teaching were related to the nature of models to (re)present specific content knowledge from the curriculum in more diverse, accessible, concrete and understandable ways. For example, the fact that models afford physical modes of representation (e.g. visual, dynamic, concrete)—as in the words of one teacher: "I need to have an image to explain things to the students … when you have to explain things to the students then you have a model … so that the students can understand reality" (B2). In general, the teachers perceived the different modes of models as fruitful artefacts to motivate different types of students (e.g. students with low reading abilities) and thus facilitate their learning of content. The teachers, in particular, held that students' understanding of content was inherently linked to the ability of models to visualise what they called "not concrete matter" or "matter you can't see"—i.e. abstract concepts such as bioaccumulation, evolution, and eutrophication, or objects (atoms), phenomena (greenhouse effect) or processes (protein synthesis) that students cannot observe directly. For example, one teacher asserted that "you can't understand" that "it takes longer to get home again from Mars [to the Earth] compared to going there […] if you do not have a model [...] because it's not necessarily logical, right?" (C1). In a similar vein, all teachers talked about models as tools for simplifying, generalising, omitting and highlighting subject content in order to aide students' content understanding. This particularly pertained to students' understanding of more complex content—as voiced by this teacher: "It is necessary to simplify very complex stuff [….] or students can't understand it […] you need to make a kind of reduction to make it easy to understand, right?" (C1). In the same way, the existence of multiple models representing the same phenomenon was addressed and related in a constructive way to students' understanding of content: "It makes really good sense [to select from among multiple models] since we use different models to communicate one or the other content knowledge. That's what we use models for - communicating complicated content … it's easier to show it in a model" (A2). Teachers' justification for addressing aspects of meta-knowledge related to the function and nature of models in the teaching was thus framed in terms of the potential to lead to students' learning of content.

Third, our data suggest that the priority given by teachers to content knowledge is related to the focus on content knowledge in the curriculum as well as in the exam. This finding is exemplified by the following quote related to the prospect of including models' limits and merits in the teaching: "We are not at this point yet… here and now, my students need to be introduced to and work with so many subject content matters [from the curriculum]" (F3). It can also be seen in the following quote: "I feel I must go through all the subjects in the textbook to make sure we cover all the goals in the curriculum" (D1). In the words of the same teacher, in her justification for highlighting a specific content aspect of the protein synthesis in her teaching with models: "It's a typical final exam question […] that's what I teach them [….] they should all be able to pass the exam [….] that's the lowest common denominator to aim for, and then we can always add more" (D1). The power of the curriculum was also manifested in the fact that concepts, elements, relationships, and processes related to the content knowledge from the curriculum dominated all teachers' narratives. Our data thus suggests that teachers' justification for using models as a means to facilitate students' learning of content knowledge hinged on curriculum as well as the exam requirements.

Although the teachers generally justified their use of models as a means to facilitate learning of content knowledge, our data also indicates deviations from this focus. As illustrated by the following quote, most teachers did recognise that meta-knowledge aspects were important for students to understand: "It is especially important to know that models can simplify reality [...] students must be able to make a critical assessment … for example, know that a model can show that but not this" (B2). For the teachers who had attended a specific course (for more detail, see research and methods section), to engage students in comparing, evaluating, and selecting from among multiple models also included a focus on developing students' meta-knowledge about models' limits and merits related to their abilities to highlight or omit elements or features of the real-world referent. This talk was, however, typically in the context of prioritising or evaluating students' understanding of content knowledge and not used as a precursor to a discussion where the model was evaluated or investigated. This notion is captured in the following exemplary statement related to how a lack of concrete correspondence between a model and its referent could lead to students' misconceptions of content knowledge:

> A2: Then we talk about what kind of misunderstandings this model [heart scale model] might give rise to […] the texture is not the same

> B2: What is this model not good at […] you might think the heart is hard…too big or painted

This priority towards students' learning of the content represented in the model seems to be the case particularly when the content knowledge was perceived as very complex. In such cases, the teachers prioritised students' understanding of the specific science content represented in a given model over and above the meta-knowledge aspects. This point is exemplified by the following passage on the relevance of integrating multiple models into teaching: "Students should not look for different models of the nitrogen cycle […] it's really hard to understand. There is no reason to confuse them" (D1), and "That would be too advanced, right?" (C1). Notice that, in this way, some teachers chose not to integrate multiple models into teaching when dealing with very complex content. This priority of content knowledge over meta-knowledge was especially dominant when the teachers talked about teaching meta-knowledge aspects to younger students: "My experience with 9th grade is really good. [...] in contrast to 7th grade...it's a challenge just to introduce what a model is" (E3). In the same vein, teachers gave priority to content knowledge over meta-knowledge when teaching students with low abilities or limited experience of models– as illustrated in the following quote on integrating meta-knowledge aspects into the teaching: "You need to consider the specific group of students. I really want to but my students' abilities set limits [...]. Last week, when I mentioned the word model, they merely related it to a fashion model" (F3). In the words of the same teacher: "It has not really been relevant. I'm rather pleased if they [the students] understand the content in the model". Yet again, as expressed by another teacher in relation to students' reflection of the tentative nature of models: "We talk about it but it's not something they think much about in their daily lives. Because knowledge is the knowledge the students have right now, that's what counts" (B2). In other words, even when the teachers found it relevant to include aspects of meta-knowledge in the teaching, they prioritised content knowledge if the students were inexperienced, young, challenged in science or the content knowledge was perceived as very complex.

The talk did therefore harbour some more or less sporadic deviations from the overarching focus on content knowledge—and these deviations seem to relate to the level of teachers' experience with models as well as students' experience, age, and ability to understand the content knowledge contained in the model. Nevertheless, the main corpus of the talk paints a picture of the teachers' practice as one in which models are predominantly included as an artefact to communicate, explain, evaluate, and facilitate students' understanding of the science content that is the focus of the curriculum and the exam. Indeed, the very *raison d'être* of including models in teaching seems by and large, for these teachers at least, to be as a means towards a greater end related to students' learning of core science content.

A Product-Oriented Versus a Process-Oriented Approach to Models

The second primary theme that emerged from the teachers' talk on the characteristics of teachers' rationales and practices was a particular approach to the way in which models were talked about and used in the teachers' self-reported classroom practices. As we show below, the teachers' narratives and teaching examples mainly reflected a product-oriented approach to models, in contrast to a process-oriented approach. Our data also suggests, however, that sometimes aspects of more process-oriented approaches were part of teachers' classroom practices. As in the case with our first theme, this second theme also manifested itself in multiple ways in the teachers' talk.

First, the product-oriented approach to models was displayed in the way teachers prioritised the use of the *different aspects of practices* with models. The most common practice for all teachers was students' use of models for the more product-oriented practices also identified in the former curriculum (i.e. for description, communication and explanation). In contrast, the more process-oriented practices such as prediction, selection, evaluation and design were used to a lesser extent. As one teacher asserted: "I and the students frequently use models to explain [...] Well it's not often that the students' design their own models...it's more like...I build the [molecular] model in advance... then the students construct a graph occasionally" (E3). Another teacher stated similarly: "Students' designing models is quite novel for me" (C1). Interestingly, the use of these process-oriented aspects of practices differed from teacher to teacher to a much greater extent than did the use of the more product-oriented aspects of practice. There is a clear pattern of more experienced teachers prioritising the process-oriented aspects more than less experienced teachers.

It is noteworthy that, while all the above-mentioned aspects of process-oriented practices from the new curriculum were enacted in varying degrees by different teachers, the process of revising models as described in the new curriculum (e.g. testing a model against reality, revising or finding another model if own or others' models do not fit the referent) had no or a very limited role in teachers' practice. For example, one teacher asserted that: "I never do that…I don't identify that practice [revising] at all in my teaching" (E3). In addition, our data suggests that some of the process-oriented practices were enacted in a rather implicit, and sometimes even unconscious, way by the more novice teachers. The latter is exemplified in the following quote: "We did use [a model of] the food chain to predict how a change would be effected…I guess we used the model for predicting…I just haven't thought about it like that before…that's what we did!" (D1). In this way, our data suggest that that not only do all the teachers prioritise product-oriented practices over the new process-oriented practices but that these new practices are also enacted (if at all) in a very implicit way by some teachers in contrast to the more uniform and explicit enactment of the product-oriented practices from the former curriculum.

The different ways of approaching these new aspects of practice were especially conspicuous in the way comparison and evaluation of multiple models was used. While most teachers used multiple models in their teaching, their frequency and how they were used fell into two categories. Teachers in the first category had no systematic, established or purposeful direct practice in terms of comparing or evaluating multiple models. If used at all, it was without a specific purpose or mainly used in an implicit or unconscious way. In general, teachers in this category were either novice at integrating more process-oriented practices with models into teaching or novice at teaching science more generally. In the second category, multiple models held a dominant position in teachers' classroom practices and were perceived as a core aspect of integrating models into teaching. For the teachers, students' comparison and evaluation of multiple models was an established, explicit, reflective, purposeful and highly valued practice in day-to-day teaching. This point is exemplified by the following quote related to students' comparison and evaluation of multiple models: "This activity always strikes home…when we have done it once then the students spot it right away next time… each model has pros and cons…you just have to do it over and over again in your teaching" (B2). An interesting point here is that all teachers with an established and valued practice of using multiple models referred to how a specific in-service course had inspired and guided this practice. This point is exemplified by the following passage about the course: "It was an eye-opening experience for both of us…despite having been a teacher for 100 years something happened to me" (A2). In the words of another teacher: "Well I did realise models have limitations …however I didn't really address it [in teaching] before the course" (B2). In this way, our data suggests that, for the teachers, an in-service course focusing on models seems to influence their teaching practice.

Second, it emerged from the interviews that *when* process-oriented aspects of practice are enacted in classrooms, they are often *enacted in a product-oriented fashion*. The following extract is illustrative of the way the teachers generally enacted the design aspect of practice: "I want the students to look at illustrations and read the text in the book […] then they make a short stop motion movie with plasticine showing the protein synthesis […] in this way they will build a dynamic model" (D1). Again, as exemplified by another teacher: "Usually, when the students are designing models it's very much like an existing model with some supplements added by the students…the models are not always inventive" (B2). Our data thus suggests that the teachers mainly implement the practice of design as adding more details to accepted models or as the construction of different modes of model based on accepted knowledge. In this way, students' design of models is reduced to replications of what is already known or solely changing the mode of model (e.g. from 2D to 3D). Indeed, activities in which students create a model based on their own predictions about the referent and then compare (and revise) the model with observations in the real world would arguably be much more process-oriented. Another interesting observation relates to how students' comparison of models was mainly based on what kind of content the model is about. This point is exemplified by the following quote related to students' activities with models from the classroom: "The students choose [a model]…what's the mode of the model? What is it able to show? And what is the model not able to show?" (B2). Along the same line, teachers typically enacted comparisons and evaluations of multiple models by means of established models and with a strong focus on illustrating different aspects of content knowledge: "I show three atomic models, the old planetary model, the orbit model, and the cloud model…and then ask the students what the different models can tell us… and not tell us?" (B2). In the words of another teacher: "What can my 2D drawing with electronic orbitals tell us?... and what about a 3D [atom model]?" (A2). As indicated above, the teachers' enacting of process-oriented aspects such as comparing and evaluating were mainly focused on whether, what and how (well) different established models represent different content aspects. In this way, models were being used and talked about as knowledge representations *of* the real world and not as an artefact *for* investigating the real world or solving a specific task.

It is important to note that the more process-oriented aspects of practice are relatively new to the Danish curriculum, and our data does indicate that some teachers are challenged by operationalising these practices in their teaching. This challenge was, in some cases, derived from a perceived lack of competence by the teachers themselves or related to a restricted understanding of how to operationalise specific practices (more on this later on). In other cases, the challenge derived from what the teachers perceived as being possible in terms of the conditions they were working under: "It's not realistic to improve a model and make a new one… It's not like a writing process back and forth… rewriting, we don't have enough time for details like that" (C1). Finally, in other cases the challenge derived from a perceived lack of guidance: "I would like to include revision of models…but I don't know how […] The web has plenty of criteria related to lab reports… but criteria for evaluation of models…no! I'm left with my gut feeling" (D1).

All teachers therefore prioritised product-oriented practices over the new process-oriented practices, although these new practices were a more frequently used and integrated teaching practice on the part of more experienced teachers than the more novice ones. In addition, when the more process-oriented practices were enacted, it was mainly in a rather product-oriented fashion, focusing on models as knowledge representations *of* the real world, and not as an artefact *for* investigating the real world or solving a specific task. In addition, our data suggests that, because of their relative novelty, the process-oriented aspects of practice with models are not implemented in a straightforward manner by the teachers and that more experience, teaching materials, courses, and guides are required to operationalise these aspects.

Third, while most of the teachers addressed multiple models as human-designed, context-sensitive artefacts designed for a specific purpose, they tended to restrict the purpose and function of multiple models to a question of showing different features of a specific phenomenon. This point is captured in this exemplary quote related to how models were discussed in the teaching: "It's the designer of the model who chooses what to highlight…in one context it's relevant to show something about energy level and orbits, in another it's relevant to show the size of electrons compared to the nucleus in the atom" (E3). Again, as asserted by the same teacher: "A model focuses on one thing rather than something else…the purpose is to focus on *this* rather than *that*" (E3). In other words, the function of multiple models typically boiled down to their descriptive purposes related to questions of whether, what or how well a model represented a specific phenomenon. Indeed, a more process-oriented approach to multiple models would be to ask what kind of questions a model would be able to answer about the observed phenomenon or how a model needs to represent the phenomenon in order to give an adequate answer to the question. The use and talk of the purpose and function of models in their teaching would thus go beyond solely focusing on the descriptive function of models.

Fourth, in all teachers' narratives, as well as in their teaching activities, they emphasised the models' affordance in terms of simplifying, illustrating and visualising the content knowledge represented in the models. By highlighting the nature of models as simplifications of, and artefacts for, showing or explaining the real world, the teachers emphasised the more product-oriented and descriptive aspects of the nature and functions of models. Some teachers did, however, address more process-oriented aspects of the nature of models in their teaching. For instance, these teachers' narratives reflected how models' tentative and progressive nature was addressed in their teaching on those occasions when historical models were found in the teaching materials they had access to and used. This notion is exemplified by the following extract related to whether and how the tentative nature of models was addressed in teaching:

> D1: Oh yes. I usually do it when teaching evolution. Then I show some of the classic models such as the 'giraffe model' [i.e. Lamarck's vs. Darwin's view of evolution exemplified by how giraffes develop their long neck]… or different models in physics about the dominant world view at different times in human history.
>
> C1: Yes, […] how you went from one understanding of the world to another, we talked about which experiments have led to new knowledge. However, that's only in 9th grade and it's not something we have paid further attention to.

Our data thus indicates that tentative and progressive aspects related to the nature of models were occasionally addressed in teachers' classroom practices. Our data also suggests that those aspects were merely addressed as a knowledge element related to historical models, and not as an applied and integrated part of students' model activities. Indeed, activities that offer students opportunities to further develop their own models based on new inquiries or a more advanced understanding would be a more process-oriented approach to students' use and understanding of the tentative and generative nature of models.

Fifth, teachers' narratives and teaching examples as a whole only sporadically mentioned how models were talked about or used as a tool for inquiry, idea generation and problem-solving, and most teachers did not explicitly identify models as a scientific practice. In general, models were not enacted as part of students' own inquiries and, if enacted, this was done in a rather restricted way only sporadically reflecting modelling as a scientific practice. For instance, students' use of models in the laboratory was merely a matter of confirming or rejecting laboratory experiment results or illustrating part of processes in established models by means of experiments. The most experienced teachers did, however, make statements in which the use of models was talked about as a scientific practice. As one teacher stated with respect to students' engagement with controlled "mini-worlds" in the laboratory: "Conducting a range of experiments is also a model of reality…we often use model-experiments" (B2). Yet again, in the words of another teacher: "It's not possible to facilitate students' abilities to do science if we only work with modelling…unless you perceive experiments as a kind of modelling […]. To do science, you need laboratory skills" (A2). An interesting point here is that our data indicates that models are only perceived as a scientific practice *if* models are implemented as experiments or share features with laboratory work. In this way, our data suggests that while the teachers did relate the use of models to scientific practices, models were still not perceived of or used as a scientific practice in and of themselves or of being of equal importance to the experiment.

Along the same line, our data suggests that the teachers mainly perceive the tentative nature of models as being a *result* of experiments and not as a scientific practice contributing to knowledge generation and knowledge review by itself. This notion is captured in this statement related to the tentative nature of models representing different world views through history: "...because it is about […] how you went from one understanding of the world to another, we talked about which experiments have led to new knowledge […] and new instruments" (C1). Our data therefore suggests that the teachers mainly perceive models as a product of new technology and the experiment as representing one universal scientific method.

In the same vein, our data suggests that some of the teachers are still challenged in terms of understanding how the different aspects of modelling practices form a part of scientific practices. This point is exemplified by the following quotes related to why revision is not part of the teachers' teaching: "It seems to me like…you know…I have respect for the already existing models in the books" (E3), and "I don't dare come up with a new model […] I really don't have the knowledge or competence to do that…" (F3). It is worth noting that the challenge facing the teachers was not only derived from their own perceived lack of competence. The quote also illustrates a very restricted way of understanding the practice of "revision" in which their only perception of enacting this aspect of practice was in terms of revising established models in textbooks. Indeed, a more advanced understanding of modelling as a scientific practice would also include the students revising their own models on the basis of their own advanced understanding, empirical data or to adjust for a specific problem to be solved. As previously mentioned, this rather restricted way of understanding modelling as a scientific practice was also reflected in the way the design aspects of modelling practice were perceived of as constructing different kinds of models based on established models or knowledge. Our data therefore suggests that the teachers largely perceive experiments as *the universal* scientific method and only sporadically recognise how modelling represents a scientific practice in itself. Our data thus suggests that teachers' restricted perceptions of scientific practices could subvert a more advanced understanding and use of models as a scientific practice in itself.

To conclude, our findings suggest that the participating teachers use and talk about models and modelling as the *product* of a scientific process rather than as *part* of a scientific process. The teachers' practices and rationales thus resemble the approach to models in the former curriculum, focusing on models as knowledge representations of the real world rather than as artefacts for students to use for a purposeful and reflective practice involving inquiry, idea generation and problem-solving.

Discussion

In this section we first discuss teachers' rationales and practices for integrating models and modelling into their teaching. We then discuss how teachers' rationales and practices align with a competence-oriented approach to model and modelling.

Teachers' Rationales and Practices for Integrating Models and Modelling into Their Teaching

One of the central findings of this study is that all the participating teachers entertained what we have called a content-orientation with regard to models and modelling—that is, when talking about how and why models and modelling were enacted in their teaching, the teachers' talk painted a picture of a teaching practice in which models were mainly justified and used as an artefact to communicate, explain, evaluate and facilitate students' understanding of content knowledge. We will discuss our findings in this respect in the following.

The teachers' justification for using models in their teaching mainly hinged on the models' ability to communicate, explain, evaluate and facilitate students' understanding and recall of the different aspects of the science content that is the focus of the curriculum. Particularly, and in line with former research (Khan 2011), all teachers perceived models as being a necessary artefact to facilitate and motivate students' understanding of complicated content knowledge. In the same vein, and aligned with Justi and Gilbert's (2002b) findings from Brazil, the nature of models was mainly valued as a pedagogical means to facilitate the learning of content knowledge. For instance, models' ability to visualise abstract concepts or processes that cannot be observed directly was valued by all teachers. Likewise, some teachers perceived the visual, dynamic, kinaesthetic and concrete modes of representations as a fruitful way to learn content knowledge and as a motivating factor to reach a range of students, including students with low reading abilities. In addition, our data suggests that teachers' prioritisation of content knowledge hinges on the curriculum, as well as the exam requirements, both of which emphasise the students' understanding of content knowledge. In this way, all the above-mentioned aspects related to the nature and function of models were solely talked about, used and valued as a pedagogical means to communicate, explain, evaluate and facilitate students' understanding of content knowledge, and not as a means for inquiry or problem-solving or for understanding the process of modelling. Our study thus resonates with previous findings among in-service and pre-service teachers, which show that the use of models in teaching is justified by pedagogical purposes related to students' learning of content knowledge (Campbell et al. 2015; Crawford and Cullin 2004; Cullin and Crawford 2002; Justi and Gilbert 2002a, 2002b; Khan 2011; Windschitl and Thompson 2006).

In line with previous research (e.g. Justi and Gilbert 2003; Miller and Kastens 2018), all the participating teachers were largely using models for descriptive purposes (i.e. describing, explaining or communicating). In contrast, and in line with prior findings (Khan 2011; Van Driel and Verloop 1999), all the participating teachers not only enacted the use of models for predictive purposes less frequently than for descriptive purposes but also did so to highly varying degrees. Another interesting finding relates to how the teachers approached the predictive features of models. Most of the teachers did not explicitly address the value or use of models' predictive function or nature. The same teachers' narratives in relation to their own teaching, however, albeit to different degrees, implied many examples of how models were being used for predictive purposes (e.g. to predict the outcomes of changing elements or variables in a food chain or a nitrogen cycle) and as representations of a hypothetical idea (e.g. historical models). This finding revealed opportunities for developing a more explicit enacting of models' predictive features (Gray and Rogan-Klyve 2018). It is important to note that neither the predictive purposes of models nor the perception of models as hypothetical entities are explicitly mentioned in the Danish curriculum. This may partly explain the teachers' varying degrees of, and rather implicit and unconscious approach to predicting. Our data does not, however, indicate whether this approach is related to the selected teachers' limited and often inconsistent knowledge of the predictive role of models in science (Justi and Gilbert 2002a; Van Driel and Verloop 1999) and/or the teachers' incomplete appreciation of predicting as relevant to teaching (Justi and Gilbert 2002b).

It is argued that the enactment of models and modelling in science education should resemble modelling as a scientific practice (Gilbert 2004; Passmore et al. 2014). This includes going beyond only enacting models as the product of a scientific practice and also involving students in the more process-oriented aspects of modelling as a scientific practice (Lehrer and Schauble 2015; Schwarz and White 2005). As outlined in our framework (Table 1), this also includes to engage students in designing, evaluating, revising, comparing and selecting models. In line with former research (Khan 2011; Krell and Krüger 2016), our findings suggest that not only prediction but also other process-oriented practices such as selection, evaluation, design and revision were used to a lesser extent than descriptive and product-oriented practices. It is also notable that designing models based on students' own empirical data, evaluating and revision of students' own models was characterised as being absent or very rarely enacted by the participating teachers. This finding suggest that the participating teachers only enact a very restricted version of the dynamic modelling process resemble modelling as a scientific practice (Schwarz and White 2005). Another notable finding is that not only do the participating teachers enact these more process-oriented practices to a lesser extent but they are also *enacted in a product-oriented fashion*, mainly focused on whether, what and how (well) different established models represent different content aspects (see more on this finding below).

The participating teachers generally prioritised students' learning of content knowledge over meta-knowledge. In line with former research (Justi and Gilbert 2003; Van Driel and Verloop 1999), however, our findings suggest that the participating teachers perceived meta-knowledge aspects related to models and modelling very differently. Indeed, although some of the less experienced teachers harboured a more restricted view (e.g. solely evaluating models based on their similarity to reality) than more experienced teachers, our findings suggest that, as a group, the participating teachers had quite a nuanced view of the nature of models. For instance, all teachers acknowledged the existence of multiple models and different modes of models, and models' abilities to simplify, visualise, omit or highlight specific features of the referent. In general, the teachers also recognised the fact that models could represent data, objects and processes as well as phenomena, and the teachers perceived of models as being human artefacts designed for a specific purpose. In addition, some teachers acknowledged models' ability to predict, generalise and represent aspects of theory. Despite this fairly advanced understanding of meta-knowledge on the nature of models, however, only a limited range and a reduced version of those aspects was perceived by the teachers as relevant for students to understand—and, if enacted at all, it was typically done with a view to students' understanding the content knowledge embedded in the model. For instance, when enacting meta-knowledge on models' merits and limitations, together with multiple models' abilities to highlight selected features of the referent, this was typically taught by prioritising students' ability to recognise merits and limitations in terms of how models could add to their own (mis)understanding of content knowledge. Similar to previous research (e.g. Campbell et al. 2015; Justi and Gilbert 2002b; Miller and Kastens 2018), therefore, not only do the teachers perceive that the main purpose of using models with students is to help them understand the content knowledge represented in the models rather than to learn about models and modelling, our study also suggests that teachers' main purpose in explicitly addressing meta-knowledge aspects in their teaching is to get the students to better understand and recognise the role that models plays with regard to explaining and learning content knowledge.

Another notable point is that even when the teachers considered that aspects of meta-knowledge were relevant for students to understand, they deselected these aspects if the students were inexperienced, young, challenged in science or if the content knowledge was perceived as very complex. This bias between teachers being aware of meta-knowledge aspects on the nature of models and yet, at the same time, deselecting these aspects in their teaching, has been identified in other studies (Justi and Gilbert 2002b; Van Driel and Verloop 1999). It has been suggested that teachers largely relate important aspects of meta-knowledge (e.g. the process of modelling) to what scientists do, and do not relate these aspects to the context of teaching, and they thus reduce meta-knowledge aspects to a question of using suitable modes of representation (Justi and Gilbert 2002a). This may also partly explain why our teachers deselect important aspects of meta-knowledge in their teaching. Our study, however, elaborates on teachers' justification for deselecting aspects of meta-knowledge by suggesting that teachers make a deliberate choice based on their prioritisation of content knowledge over meta-knowledge. In addition, teachers' fairly advanced understanding of meta-knowledge on the nature of models revealed opportunities for developing a more explicit and advanced enacting in this regard (Gray and Rogan-Klyve 2018).

The enhanced focus on modelling in the Danish curriculum resemble an international trend towards modelling playing an increasingly prominent role in science education curricula (Campbell and Oh 2015; NRC 2012). As discussed above, the characteristics of how and why the participating teachers enacted models and modelling are not unique to a Danish context but resemble many of the issues raised in other international studies related to teachers' treatment of models and modelling in science education. Our findings also contribute to research suggesting that curriculum changes do not result by themselves in classroom practices but are influenced and challenged by a wide range of factors, including teachers' existing practices (Lehrer and Schauble 2015), experience and routine (Krell and Krüger 2016; Schwarz and Gwekwerere 2007), and the way they perceive the nature of science (Windschitl and Thompson 2006)—including a restricted perception of modelling as a scientific practice (Kenyon et al. 2011; Vo et al. 2015). Our study also suggests that the teachers encountered challenges in enacting the revised curriculum deriving from their own perceptions of their limited competence, inadequate teaching conditions and lack of guidance. In addition, our findings resonate with earlier research indicating that the approach in existing teaching materials (Gouvea and Passmore 2017) and courses (Günther et al. 2019; Schwarz and Gwekwerere 2007) influences teachers' enactment of the curriculum.

Alignment between Teachers' Practices and Rationales and a Competence-Oriented Approach to Models and Modelling

Applying the concepts of competence (cf. Busch et al. 2004) and action (Nielsen and Gottschau 2005) to students' engagement with models and modelling implies a *reflective* and *applied use* of different aspects of knowledge and practices purposefully directed at *solving a subject-specific problem or task* in *different situations*. As outlined in our modelling competence framework (Fig. 1) constructed from existing research, the different aspects that characterise a competence-oriented approach to models and modelling can be related to three main elements: *subject-specific knowledge represented in models*, *meta-knowledge of models and modelling*, and *modelling practices.* While our findings show that the participating teachers' practices and rationales for integrating models and modelling into their teaching practice address all three elements, our findings also suggest that the teachers' approach is characterised by a product-oriented approach not well aligned with competence-oriented teaching. The product-oriented approach manifested itself in two distinct ways: (a) The enactment of models and modelling in teaching was justified by pointing to the affordance of models as artefacts that can facilitate students' learning of content knowledge; and (b) the teachers' talk suggested that they treat models as the *product* of a scientific process rather than as *part* of a scientific process.

The participating teachers' product-oriented approach to modelling thus implies a teaching practice in which there is a focus on subject-specific content knowledge. Now, this knowledge may be "embedded" in, or represented by, a model, but, if so, this is primarily because embedding the knowledge in a model may aid students' acquisition of that knowledge. It is difficult to see how this type of practice is competence-oriented. Indeed, according to Kind and Osborne (2017), a product-oriented approach will mainly provide students with lower-order cognitive challenges of recall, comprehension and application. This knowledge generation is considered passive (cf. Ropohl et al. 2018) and is not very fruitful at contributing to competence-oriented teaching where the emphasis is on reflection and on solving a specific problem or task (Nielsen and Gottschau 2005). In addition, when models are solely introduced into the classroom as representations of what is known rather than as active tools for inquiry, students' prospects for engagement in applied scientific practice and problem-solving will be reduced (Passmore et al. 2014). From this perspective, the participating teachers' approach to models and modelling also reflects former approaches to science education dominated by content knowledge of the models without developing an understanding of the processes that led to the knowledge embedded in the model, or the purposes, value and utilisations of models in science (Kind and Osborne 2017; OECD 2017).

As implied above, the participating teachers' product-oriented approach to modelling indicates that their teaching contains only minimal prospects for students in terms of understanding and applying the central aspects of meta-knowledge as illustrated in Fig. 1. More specifically, our findings suggest that the participating teachers mainly enact meta-knowledge related to models as a means for communication and students' sensemaking of content knowledge. While this kind of meta-knowledge is considered important in competence-oriented teaching (Papaevripidou, Nicolaou and Constantinou 2014; Schwarz et al. 2009) it is not considered sufficient. A competence approach to modelling also requires some kind of reflection related to the specific modelling practices in science and the rationale for students to engage in these practices, since students should be aware of what they are doing and why (Schwarz et al. 2009; Schwarz and White 2005). Along the same lines, it has been argued that the major steps in the process of scientific modelling should play an important role in science teaching when working with meta-knowledge (Lehrer and Schauble 2015). The purpose, value, and utilisation of models in society are likewise considered to be central in competence-oriented teaching (Miller and Kastens 2018; Valk et al. 2007; Windschitl and Thompson 2006). Including meta-knowledge related to the use of models in research and society goes beyond students' reflecting on the models' usefulness in terms of their descriptive functions. This kind of meta-knowledge holds the prospect of developing students' understanding of how models could be used as hypothetical entities used to "grapple with" and develop new ideas of how the world works and how they could be purposefully used in solving subject-specific problems or tasks in different situations—all important aspects of a teaching that is aimed at developing students' modelling competence.

Like other scholars (Grünkorn et al. 2014; Nicolaou and Constantinou 2014; Schwarz et al. 2009; Van Driel and Verloop 1999), we find the predictive use of models a salient aspect to include in a competence-oriented approach to models and modelling. Indeed, we advocate that the predictive function of models should be given a key position in this regard. For instance, the predictive function holds the prospect of designing and using models to explore and raise new questions and hypotheses about a phenomenon, predicting 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 investigative or problem-solving purposes. Indeed, all the participating teachers' limited enactment, and for a subset of the teachers combined with an implicit or even unconscious enactment of models' predictive affordance, indicate a teaching that is not utilising the full range of opportunities for teaching for modelling competence.

In addition, the product-oriented approach indicates a teaching that mainly provides students with opportunities to engage in the descriptive functions of modelling (i.e. describing, explaining and communicating) but only offers minor prospects for using models for predictive and problem-solving purposes (see Table 1). The product-oriented approach likewise limits students' opportunities for developing and applying their meta-knowledge and content knowledge. These opportunities could be used in students' own engagement in the process of modelling, for instance by developing models that embody theory and data, evaluating models, and revising models to accommodate new theoretical ideas or empirical findings (Baek and Schwarz 2015; Schwarz and White 2005).

By contrast, a process-oriented approach to models and modelling shares many similarities with Gouvea and Passmore' (2017) "*models for*" teaching approach, with a strong reference to the epistemic functions of models (what they are for). In this kind of teaching, the focus is on models as tools for dealing with scientific tasks and issues, for example, models' nature and use in prediction, problem-solving, discussion, question raising, and reasoning. This approach to teaching focuses on the more process-oriented meta-knowledge aspects (e.g. the value of modelling for prediction or inquiry purposes, designed for a specific purpose) and would also contribute to a more competence-oriented teaching by facilitating students' understanding and reflection on why they are doing what they are doing rather than learning a set of "scientific practice" rules and procedures (Berland et al. 2016; Schwarz et al. 2009). Based on the above, we would argue that the participating teachers' valuing of models solely as a means to facilitate the learning of core science content rather than meta-knowledge and their rather product-oriented approach to models and modelling challenge the possibilities of enacting the intentions of the new competence-oriented Danish school curriculum.

Implications and Conclusions

In line with previous research, our findings suggest that it is not a straightforward process for teachers to translate the complex process of scientific modelling into their science classrooms (e.g. Svoboda and Passmore 2013), nor to change the teachers' perception of the process of scientific inquiry (Windschitl et al. 2008) and school science (Miller and Kastens 2018), nor to shift teachers from undertaking a product-oriented approach towards a competence-oriented approach in their science teaching (e.g. Nielsen & Dolin 2016; Sølberg et al. 2015). Indeed, it must be considered a tall order given that not only are models and modelling very complex concepts (Schwarz et al. 2009) but, on top of this, science teachers are also being requested to add a complicated and poorly-defined competence-oriented approach to their teaching (Ropohl et al. 2018).

The assumption of this study is that the degree of alignment between theoretical intentions and arguments for integrating models and modelling into science education, on the one hand, and teachers' practices, rationales and conditions, on the other, significantly affects the prospects for and challenges facing teachers in adopting a competence-oriented modelling teaching practice. This study indicates a "gap" in this alignment. If we want to narrow this gap, we have to consider the challenges and prospects on each side. This study highlights the following areas for consideration: *In-service and pre-service educators* should utilise teachers' well-established modelling practices and rationales and extend them by introducing minor adjustments that would make teachers' practice more process-oriented. It should also be clearly explained to the teachers how these adjustments will help facilitate students' learning of content- *and* meta-knowledge. Using teachers' current practice and rationales as a starting point would also be in line with recommendations for how to facilitate teachers' motivation for and adaption of new approaches to teaching (Janssen et al. 2014). As argued by Janssen et al. (2014) classroom inventions connecting to and building on what teachers already acknowledge, know and can do would be a concrete, attainable and sustainable strategy to adopt new teaching approaches. In this light, teachers' existing practice of comparing and evaluating multiple models could be a good starting point. This could be done by channelling teachers' existing descriptive model *of* practice with multiple models towards a more process-oriented model *for* practice that focuses on multiple models' affordances in terms of raising, answering, predicting or solving different ideas, tasks and problems.

In addition, teachers' restricted perceptions and use of modelling as scientific practice could be addressed by combining modelling with the well-established practice of experiments, observations, laboratory and field work. For instance, by crafting testable predictions with models, empirically testing models against data, or designing, evaluating and revising models based on empirical data, theoretical considerations or new purposes. This would raise awareness of the role models play as a scientific practice and, at the same time, enrich the way in which teachers perceive the nature of scientific inquiry as only being represented by *the universal* scientific method.

We suggest that *curriculum designers*: (a) adapt the existing curriculum to match the number of teaching hours; (b) position and specify modelling as a scientific practice equal to *the* scientific method; (c) operationalise modelling competence to a greater degree; (d) emphasise the predictive nature and role of models; (e) highlight how students' understanding of content knowledge *and* meta-knowledge could be facilitated through a purposeful, task- and problem-oriented engagement with models; and (f) reconsider how to support teachers in the process from understanding to adopting the curriculum by means of teaching examples and materials aligned with the new curriculum intentions. Finally, we recommend a better alignment between the current exam and a competence-oriented teaching approach.

Limitations

This study is based on the participating teachers' talk together with the other teachers and the interviewer about their own classroom practice. Clearly, we do not know if these discussions depict a genuine picture of these teachers' practice. Indeed, in our further work we are planning to compare these teachers' talk with their actual classroom practice. We have several reasons to believe, however, that the teachers intended to give us a true picture of their own practice. First, the interviews are part of a wider study aimed at developing their teaching with models and modelling by using their present teaching as a point of departure. Second, the framing of the interviews as reflection sessions on their own teaching produced narratives very close to teachers' actual practice, with numerous classroom examples. Finally, the teachers' talk reported in this paper is only one of several data sources from the wider study and, although these other data sources (teaching materials, classroom observations) are not included in this paper, insights from these sources have informed our understanding of these teachers' practice. While we believe the teachers intended to give us a true description of their actual practice, we also understand that their intentions may not have been fully achieved due to their limited understanding of the different aspects of modelling practices and concepts related to meta-knowledge aspects. For future research, we therefore suggest that scholars investigate how teachers' interpretations of practices and concepts related to models and modelling as a competence (e.g. design, prediction and nature of models) influence how they perceive of and refer to their own teaching.

Our small sample size means that our findings are highly contextualised within the three specific schools and related to the six teachers' personal history (e.g. in-service training, teacher education, teaching experience, total number of science teaching subjects) and are, among other things, also probably influenced by these teachers' approach to teaching in general. In addition, the "convenient" and "volunteer" aspects of the allocation process must be considered to be selective and biased and, consequently, means that the results demonstrate limited representativeness of science teachers. Further research should include a larger and more representative sample of Danish teachers. Nevertheless, despite these limitations, we think that the high amount and level of detail and nuances in this study allows us to identify some important patterns related to different Danish science teachers' practice and rationale for integrating models and modelling into their teaching in diverse school contexts.

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Appendix. Examples of statements used to facilitate teachers' reflections on why and how to integrate models and modelling into their current and forthcoming teaching

- Students use models to explain a certain phenomenon.
- Students use models as a tool for hypothesis generation.
- Students choose between multiple models to solve a task or problem.
- Students compare multiple models concerning the same phenomenon.
- Students compare models with the phenomenon it represents.
- Students use models for predicting how a certain phenomenon could develop (e.g. over time or in a different context).
- Students create their own models.
- Students create models based on their own inquiries.
- Students revise their own or others' models.
- Students reflect on why models are not fixed.

- Students evaluate the limitations and scope of certain models related to purpose.
- Students reflect on the value of models related to their own learning.
- Students reflect on when it makes sense to create a model.
- Use of models offers prospects for improving science education.
- Models can facilitate students' abilities to work scientifically.

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Paper 4.

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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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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

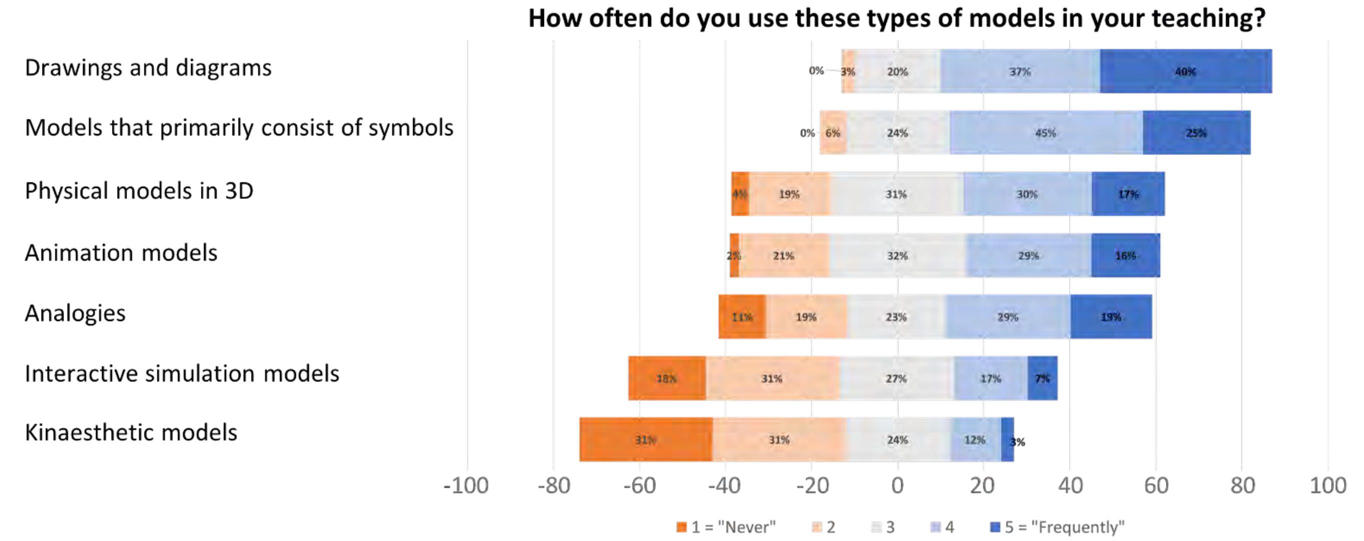

Figure 1. Diverging stacked bar chart of teachers' responses to how frequently teachers use six different types of models when models are part of the teaching (n = 238 teachers). Categories ranged from 'Never' to 'Frequently'. 'Frequently' was defined as 'almost every time models are used in your teaching'.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

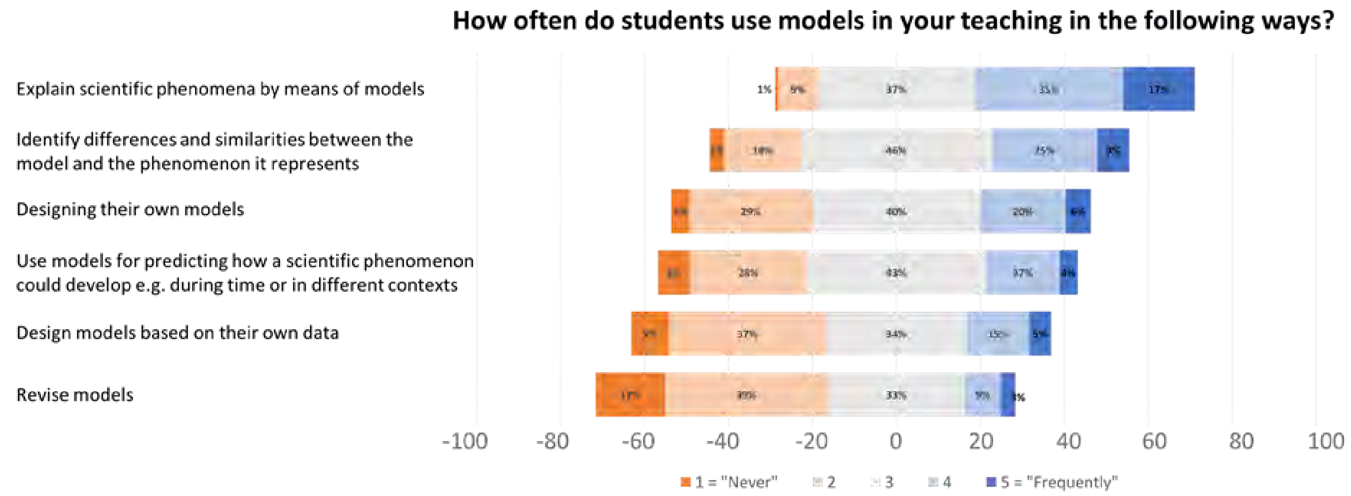

Figure 2. Diverging stacked bar chart of teachers' responses to how frequently students used six specific aspects of modelling practices when models were part of the teaching (n = 235 teachers). Categories ranged from 'Never' to 'Frequently'. Frequently was defined as 'almost every time models are used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

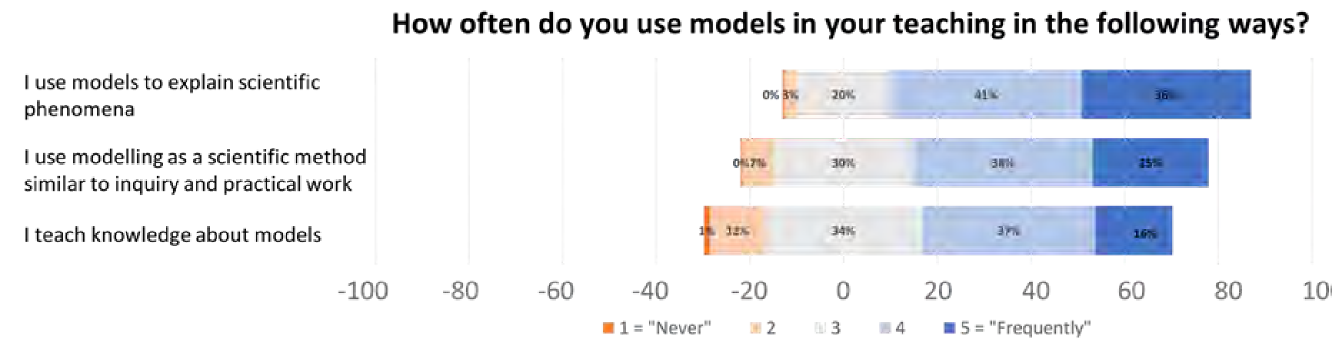

Figure 3. Diverging stacked bar chart of teachers' responses to how frequently they address the three overall learning goals of science education mentioned in the curriculum when they use models in their teaching (n = 238 teachers). Categories ranged from 'Never' to 'Frequently'. Frequently was defined 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

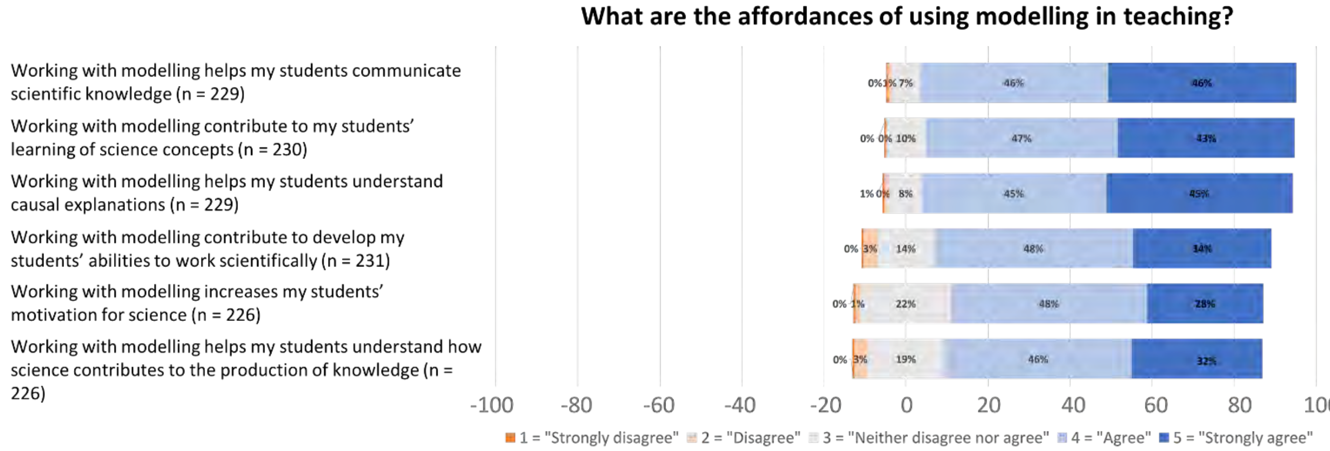

Figure 4. Diverging stacked bar chart of the level of teachers' agreement with whether or not using modelling has specific student-outcome affordances. Percentages are centered around the middle frequency category. 'Don't know' responses were excluded – the n-value thus varies

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.

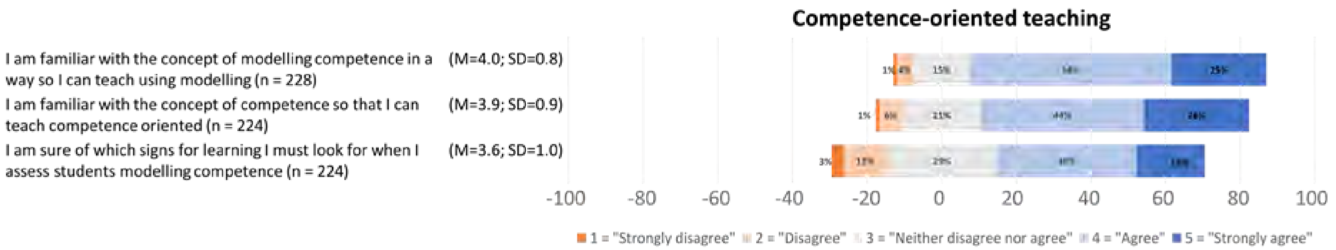

Figure 5. Diverging stacked bar chart of the level of teachers' agreement with statements about their ability to teach for (modelling) competence. Percentages are centered around the middle frequency category. 'Don't know' responses were excluded – the n-value thus varies

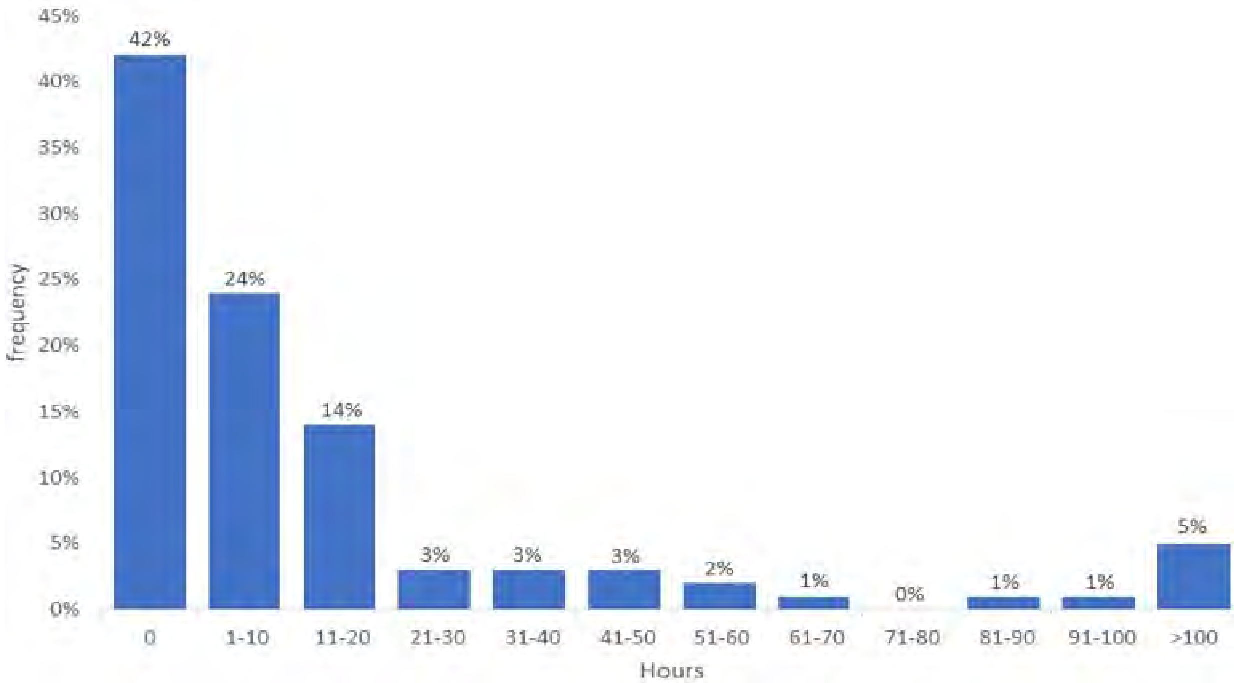

Figure 6. Frequency of the total number of hours of in-service training in science approved by the local school authority over the last three years (n = 246)

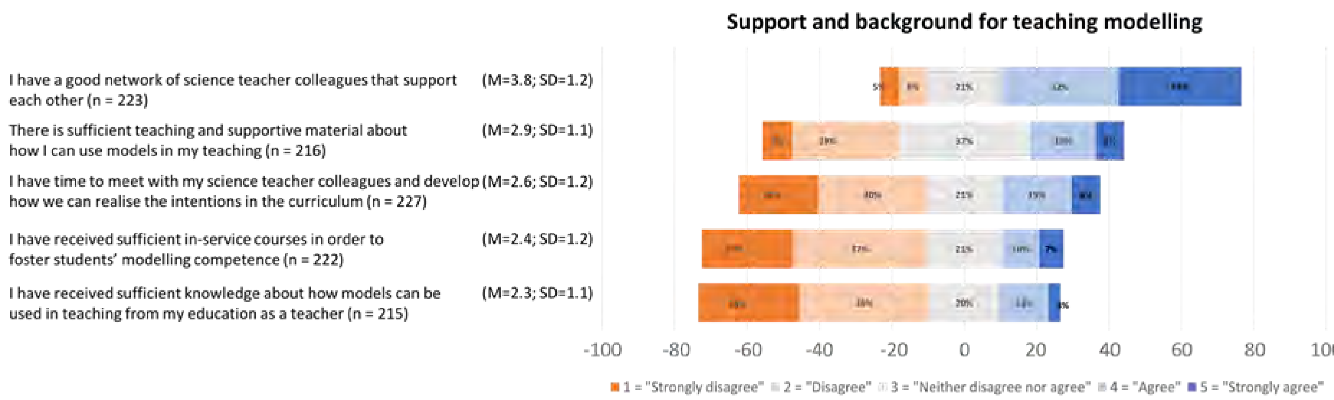

Figure 7. Diverging stacked bar chart of the level of teachers' agreement with statements about support and their background for teaching modelling as described in the curriculum. Percentages are centered around the middle frequency category. 'Don't know' responses were excluded – the n-value thus varies

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.

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Appendix

Appendix 1. Dates and schools for data sampling

Table showing the date and the school for the different data sampling activities in the school-based part of the research project. Each school, is indicated by a number (1 to 3). Asides from a few exceptions do to practical challenges all activities were conducted in teacher pairs of two at each school.

Activities	**School and date**
Upstart session with paper version questionnaire	1:14/6 2016 2: 16/6 2016 3: 30/11 2016
Session with semi-structured interviews	1: 9/9 2016 2: 6/9 2016 3: 21/12 2016
Workshop 1: Planning session Learning goals	1: 23/9 2016 2: 20/9 2016 3: 1/2 2017
Workshop 2: Planning session Rubrics	1: 8/11 2016 2: 27/9 2016 3: 8/2 2017
Workshop 3: Planning session Modelling activities	1: 22/11 2016* 2: 31/1 2017 3: 2/11 2017*
Workshop 4: Reflection session	2: 25/1 & 21/3 2017 3: 8/5 2017*
Workshops supplementary	2: 15/3 2017 & 21/3 2017

*Only one teacher

Table showing the date, the teacher and the school for the classroom observations in the school based part of the research project. Each teacher is given an individual code in the form of a letter (A, B, C, etc.). In addition, teachers are identified by school, by a number (1 to 3). The reference 1A thus denotes teacher 'A' from school 1.

Date classroom observation		**Teacher and school**
2016	26/9	C1
	04/10	D1
	06/10	C1
	10/10	C1
	10/11	D1
	11/11	A2, B2
	17/11	C1
	24/11	*B2*
2017	20/1	*C1*
	21/2	*F3*
	3/4	*F3*
	8/5	*F3*

Appendix 2. Examples of statements used to facilitate teachers' reflections

Examples of statements used to facilitate teachers' reflections on why and how to integrate models and modelling into their present and forthcoming teaching.

- Students use models to explain a certain phenomenon.
- Students use models as a tool for hypothesis generation.
- Students choose between multiple models to solve a task or problem.
- Students compare multiple models concerning the same phenomenon.
- Students compare models with the phenomenon it represents.
- Students use models for predicting how a certain phenomenon could develop (e.g. during time or in a different context).
- Students create their own models.
- Students create models based on their own inquiries.
- Students revise their own or others' models.
- Students reflect on why models are not fixed.
- Students evaluate limitations and scope of certain models related to purpose.
- Students reflect on the value of models related to their own learning.
- Students reflect on when it makes sense to create a model.
- Use of models holds prospects for improving science education.
- Models can facilitate students' abilities to work scientifically.

Appendix 3. Teacher generated learning goals

Teacher generated learning goals in Danish. Each teacher is given an individual code in the form of a letter. In addition, the teachers are identified by school, by a number.

- Du kan med relevante fagbegreber gøre rede for menneskeskabte aktiviteter, der øger den globale opvarmning ud fra en model (F3)
- Ud fra modeller af kulstofs kredsløb kan du beskrive enkelte kemiske processer (A2)
- Kan beskrive opbygningen af molekyler i fotosyntesen (A2)
- Forstå naturfaglige fænomener vha. modelforsøg (B2)
- Anvende en model af kvælstoffets kredsløb til at beskrive og forklare elementerne og de kemiske processer mellem elementerne i modellen (B2)
- Du kan forklare, hvad de enkelte elementer i modellen repræsenterer i virkeligheden (B2)
- Du kan forklare en kemisk delproces i nitrogens kredsløb i detaljer med den rigtige terminologi og beskrive, hvor processen foregår i den store overordnede N-kredsløbsmodel (C1)
- Du kan vise og forklare hvordan kæden af aminosyre sættes sammen og bliver til et protein vha. din model (D1)
- Du kan opstille nogle forsøg, der afspejler nogle processer i modellen (F3)
- Du er i stand til at vælge den model, som er bedst egnet til at give svar på et bestemt spørgsmål (F3)
- Du kan sammenligne forskellige carbon modeller og med fagbegreber beskrive, hvad de viser noget om, og hvad de ikke viser noget om (F3)
- Du kan forholde dig til hvilke styrker og svagheder, der er ved en bestemt model ift. at give svar på et bestemt spørgsmål (F3)
- Udvikle en eksisterende C-model så den bliver mere detaljeret i særlige dele og mindre i andre dele (F3)
- Kan skelne ml. betydningen af forskellige pile i udvalgte modeller og overføre denne viden til ukendte modeller (A2)

- Kan ud fra modeller af carbons kredsløb designe forsøg, der viser enkelte kemiske processer i modellen (A2)

- Kan vurdere specifikke carbon relaterede modellers muligheder og begrænsninger (A2)

- Eleverne kan anvende en model af kulstof kredsløb til at udvikle egne forsøg med hypotesedannelse (A2)

- Kan sammenligne en model med virkeligheden og se, hvor der er overensstemmelse, og hvor der ikke er overensstemmelse (B2)

- Forudsige hvordan ændring i et element i N-kredsløbet påvirker andre elementer (C1)

- Fremstille en 2D-model af kvælstoffets kredsløb sammen med din gruppe; modellen skal vise de kemiske delprocesser med korrekt terminologi (C1)

- Relatere småforsøg til en overordnet model af N-kredsløbet (C1)

- Kan fremstille en dynamisk model af proteinsyntesen, som er let at forstå for de andre elever og fagligt korrekt (D1)

- Eleven kan vælge de væsentligste celle-organeller ud til deres dynamiske model af proteinsyntesen (D1)

- Kan bruge deres model til at forudsige, hvad der sker, hvis der falder en base ud af DNA (D1)

- Elever har viden om, at en model er en forsimplet repræsentation af virkeligheden (A2)

- Forstå at en model er en forsimplet repræsentation af virkeligheden (B2)

- Forstå at forskellige kendte og ukendte modeller, som ser forskellige ud, kan repræsentere det samme fænomen (B2).

Appendix 4. Teacher generated rubrics

	To know and describe	To understand and apply	To analyse and generalize
Modelling	Can compare components of the model with the real world. Know that a model is a simplified representation of a part of the real world.	Use models for understanding scientific phenomena. Can evaluate usefulness and restraints of different models.	Can develop a specific model with more levels of details. Can make generalizations based on unknown models.
The chemistry in the carbon cycle	Describe a carbon cycle model and some of its chemical carbon composition.	Can extend a model of the natural processes in the carbon cycle with human impacts. Use the model for understanding and explaining simple chemical processes represented in the model.	Can compare and analyse how the chemical processes in multiple-models of the carbon cycle are described/represented.
Practical inquiries	Can conduct simple practical inquiries and use a model to demonstrate where the inquiries are related to the real world.	Can conduct simple practical inquiries and use a model to explain how the data are related to the real world.	Can use a carbon cycle model for developing their own practical inquiries and for hypothesis generation.

Content	5 points	3 points	1 point
Model: Chemical equations	Can describe, balance and explain the chemical equation for each of the three chemical reactions: ammonia to ammonium; ammonium to nitrite; nitrite to nitrate	Can describe less than three of the chemical equations or describe all three with mistakes	Have no chemical equations
Model: Nitrogen cycle	Can explain the six key elements in the model with the correct terminology	Can in own words correctly explain five elements in the model	Can in own words correctly explain less than five elements in the model

Appendix 5. Questionnaire

Modellering, Fælles Mål og evaluering i udskolingens naturfag
Spørgeskemaet er opdelt i fire dele. Den første del handler om din undervisnings- og uddannelsesbaggrund. Den anden del handler om, hvordan du anvender modeller i din undervisning. Den tredje del handler om din evaluering og dine muligheder for at implementere Fælles Mål i praksis. Den sidste del handler om din holdning til fællesfaglige tiltag. Du kan bevæge dig frem og tilbage i skemaet ved hjælp af knapperne.

Uddannelsesbaggrund
Læreruddannelse med linjefag eller merit i følgende fag
(1) ❑ Biologi
(2) ❑ Geografi
(3) ❑ Fysik/kemi
(4) ❑ Natur/teknologi

Anden uddannelse eller efteruddannelse inden for naturfag
(5) ❑ Vejlederuddannelse (fx naturfagsvejleder eller lign.)
(2) ❑ Pædagogisk diplomuddannelse i naturfag (et eller flere moduler)
(1) ❑ Naturvidenskabelig universitetsuddannelse
(4) ❑ Anden uddannelse

Uddyb evt. anden uddannelse

Hvor mange timer har din ledelse samlet bevilliget til din efteruddannelse indenfor naturfag de sidste 3 skoleår?
(1) ❑ 0
(2) ❑ 1-10
(3) ❑ 11-20
(4) ❑ 21-30
(5) ❑ 31-40
(6) ❑ 41-50
(7) ❑ 51-60
(8) ❑ 61-70
(9) ❑ 71-80
(10) ❑ 81-90
(11) ❑ 91-100
(12) ❑ Mere end 100

Undervisningserfaring i naturfag
(1) ❑ Mindre end 5 år
(2) ❑ Mellem 5-10 år
(3) ❑ Mellem 11-20 år
(4) ❑ Mere end 20 år

Undervisningserfaring i følgende naturfag i mindst et skoleår.
(1) ❑ Biologi
(2) ❑ Geografi
(3) ❑ Fysik/kemi
(4) ❑ Natur/teknologi
(5) ❑ Ingen erfaring

Hvor mange af dine skemalagte timer er naturfagsundervisning i udskolingen i indeværende skoleår

(1) ❑ 0
(2) ❑ 1-5
(3) ❑ 6-10
(4) ❑ 11-16
(5) ❑ 17 eller mere
(6) ❑ Det ved jeg ikke

Resten af spørgeskemaet skal kun besvares ud fra din undervisningserfaring i et af de 3 naturfag i udskolingen. Sæt kryds ved det fag, som du vil besvare spørgeskemaet ud fra.

(1) ❑ Biologi
(2) ❑ Geografi
(3) ❑ Fysik/kemi

Du er nu nået til anden del af spørgeskemaet. Den handler om brug af modeller i din undervisning. "Hyppigt" betyder næsten hver gang, når du anvender modeller i din undervisning. (spørgsmålet bliver gentaget tre gange da eksemplerne er målrette til de tre forskellige faggrupper, her medtages kun for biologi**)**

	Aldrig				**Hyppigt**
Fysiske 3D modeller fx torso	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Tegninger og diagrammer fx illustration af blodkredsløbet	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Modeller som primært består af symboler fx fotosynteseligningen	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Animationsmodeller fx proteinsyntesen	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Interaktive simuleringsmodeller fx klimamodeller, hvor eleverne kan ændre på forskellige variabler	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Analogier fx analogien mellem en pumpe og et hjerte	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Kinæstetiske modeller fx eleverne agerer forskellige atomer, molekyler og tilstandsformer i fotosynteseligningen	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

Her kan du skrive eksempler på konkrete modeller, som du arbejder med i din undervisning

Hvor ofte bruger du modeller i din undervisning på følgende måder? "Hyppigt" betyder næsten hver gang, når du anvender modeller i din undervisning.

	Aldrig				Hyppigt
Jeg forklarer naturfaglige fænomener vha. modeller	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Jeg anvender modellering som en naturvidenskabelig arbejdsmetode på linje med det undersøgende og praktiske arbejde	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Jeg inddrager viden om modeller i undervisningen fx samme fænomen kan repræsenteres med forskellige modeller eller styrker og svagheder i modeller	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

Hvor ofte bruger eleverne modeller i din undervisning på følgende måder? "Hyppigt" betyder næsten hver gang, når de anvender modeller i din undervisning.

	Aldrig				Hyppigt
Eleverne forklarer naturfaglige fænomener vha. modeller	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Eleverne identificerer forskelle og ligheder mellem modellen og det fænomen, modellen repræsenterer	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Eleverne fremstiller deres egne modeller	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Eleverne bruger modeller, når de skal forudsige, hvordan et naturfagligt fænomen vil udvikle sig fx over tid eller under forskellige forhold	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Eleverne fremstiller modeller baseret på resultater fra deres egne undersøgelser	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Eleverne reviderer modeller	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

De næste spørgsmål handler om dine erfaringer med modeller i undervisningen. Angiv hvor uenig eller enig, at du er i udsagnet.

	Meget uenig	**Uenig**	**Hverken eller**	**Enig**	**Meget enig**	**Ved ikke**
Arbejde med modellering øger mine elevers motivation for naturfag	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Arbejde med modellering bidrager til mine elevers læring af faglige begreber	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Arbejde med modellering bidrager til at udvikle mine elevers evner til at arbejde med naturvidenskabelige arbejdsmetoder	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Arbejde med modellering hjælper mine elever med at forstå, hvordan naturvidenskaberne skaber viden	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Arbejde med modellering hjælper mine eleverne, når de skal kommunikere naturfaglig viden	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Arbejde med modellering hjælper mine elever til at forstå årsagssammenhænge	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑

De næste spørgsmål handler om i hvilken udstrækning, du føler dig "klædt på" til at implementere kravene i Fælles Mål (FM) om at udvikle elevernes modelleringskompetence. Angiv hvor uenig eller enig, at du er i udsagnet.

	Meget uenig	**Uenig**	**Hverken eller**	**Enig**	**Meget enig**	**Ved ikke**
Jeg er fortrolig med kompetencebegrebet, så jeg kan undervise kompetenceorienteret	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Jeg er fortrolig med modelleringskompetencebegrebet, så jeg kan undervise med modellering	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Jeg er sikker på, hvilke tegn på læring jeg skal kikke efter, når jeg evaluerer elevernes kompetencer til at arbejde med modeller	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Der er tilstrækkeligt med undervisningsmateriale og understøttende materialer, som omhandler, hvordan jeg kan anvende modeller i min undervisning	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Gennem læreruddannelsen har jeg fået den nødvendige viden om, hvordan modeller kan anvendes i undervisningen	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Jeg har fået tilstrækkelig efteruddannelse ift. at udvikle elevernes modelleringskompetence	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Jeg har et godt netværk af naturfagskollegaer, som støtter hinanden fagligt	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Jeg har tid til at mødes med mine naturfagskollegaer og udvikle, hvordan vi kan realisere intentionerne i FM	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑

I feltet kan du skrive, hvis du har kommentarer til i hvilken udstrækning, det er muligt at realisere intentionerne i Fælles Mål.

Hvordan har indførelsen af de fire kompetencemål i Fælles Mål (FM) i 2014 ændret din undervisning, og i hvilken udstrækning mener du, at indførelsen er relevant?

	Meget uenig	Uenig	Hverken eller	Enig	Meget enig	Ved ikke
Indførelsen af kompetencemålene har betydet, at jeg har mere fokus på modellering end før FM	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Hvis to eller flere af de fire kompetenceområder spiller sammen i undervisningen, styrkes naturfagsundervisningen	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Jeg mener kompetencetilgangen er en god måde at gribe naturfagsundervisningen an på	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Jeg mener, at der er en modsætning mellem at arbejde målorienteret og at fremme elevernes naturfaglige dannelse	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑

Her i feltet kan du skrive, hvis du har kommentarer til spørgsmålene.

Du er nu nået til tredje del af spørgeskemaet. Den handler om din evaluering generelt.

Som løbende (formative) evalueringsformer anvender jeg:

	Aldrig				Hyppigt
Skriftlige opgaver	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Tests tilpasset min undervisning	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Mundtlig dialog	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Elev -til -elev feedback	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Elev-selvevaluering	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

Her i feltet kan du skrive, hvis du har kommentarer til spørgsmålene. Fx dine rammebetingelser mht. at arbejde med løbende evaluering.

Når jeg arbejder med løbende evaluering:

	Aldrig				Hyppigt
Diskuterer jeg læringsmål med eleverne	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Diskuterer jeg evalueringskriterier med eleverne	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Tilpasser jeg feedbacken til den enkelte elevs behov	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Sikrer jeg, at feedbacken bliver brugt fremadrettet af eleverne	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Ledsager jeg min evaluering med en karakter i 8. og 9. klasse	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

Her i feltet kan du skrive, hvis du har kommentarer til spørgsmålene. Fx dine rammebetingelser mht. at arbejde med løbende evaluering.

Angiv hvor uenig eller enig du er i udsagnet

	Meget uenig	Uenig	Hverken eller	Enig	Meget Enig	Ved ikke
De fire fælles kompetenceområder styrker det fællesfaglige samarbejde mellem geografi, fysik/kemi og biologi	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Den fælles faglige prøve styrker naturfagene	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Det er fornuftigt gradvis at arbejde mod et fælles science fag for 7.-9. klasse	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Jeg har de nødvendige forudsætninger for at undervise i et fælles science fag	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑
Et fælles science fag giver bedre mulighed for at arbejde med autentiske problemstillinger sammenlignet med tre fagopdelte fag	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(1,000) ❑

Her i feltet kan du skrive, hvis du har kommentarer til spørgsmålene.

Her i feltet kan du skrive, hvis du har uddybende kommentarer til spørgeskemaet.

Supplerende oplysninger

Skolens elevtal i undervisningsåret 2016/17

(1) ❑ Under 200
(2) ❑ 200-400
(4) ❑ 401-600
(5) ❑ 601-800
(9) ❑ over 800
(10) ❑ Det ved jeg ikke

Jeg vil gerne have den færdige rapport tilsendt sammen med forslag til undervisningsaktiviteter. Materialet vil være klar til efteråret.

(2) ❑ Ja via mail
(3) ❑ Nej

Må vi kontakte dig for at få uddybning af nogle af dine svar

(2) ❑ Ja via mail
(1) ❑ Nej

Tak for din deltagelse
Afslut din besvarelse ved at klikke på afslut.