Alignment between teachers’ practices and political intentions in the context of a reformed modelling-oriented science curriculum in Danish lower secondary school

Abstract
A new national science curriculum for lower secondary education was initiated in Denmark in 2015-2016. The intentions behind the new curriculum include substantial changes to how teachers should address models and modelling (MoMo) in their practice. This study focuses both on those intentions and on teachers’ practices, rationales, and experiences in this regard. Data were generated by means of semi-structured interviews and lesson planning workshops among three pairs of teachers. Our findings suggest that: (1) teachers’ practices and rationales for integrating MoMo into their teaching reflected an approach by which MoMo were treated largely as the product of a scientific process rather than part of a scientific process; (2) the dynamic process of designing, evaluating and revising models based on students’ own inquiry only played a minor role; and (3) teachers had multiple experiences in their efforts to enact the curriculum intentions. Finally, based on the findings, we discuss how to enhance the alignment between curriculum intentions and teachers’ practice.

BACKGROUND AND RESEARCH QUESTIONS
We have argued in previous publications that science is first and foremost a ‘modelling enterprise’ and that modelling ought to be the core scientific practice in school science (e.g. Nielsen & Nielsen, 2019; 2021). Indeed, models as products and modelling processes are important for science teaching
because both – i.e. models (as products) and modelling (processes) (hereafter MoMo) – can facilitate conceptual learning, scientific reasoning, inquiry competence and general knowledge of the nature of science (e.g. Gilbert & Justi, 2016).

Scientific practice, including modelling, has played a prominent role in the science curriculum worldwide (Campbell & Oh, 2015; NRC, 2012). These increasing efforts to engage students in a wide range of scientific practices also represent a shift in the key learning goals of science education from students acquiring knowledge to students acquiring and using that knowledge (Berland et al., 2016). Indeed, rather than separately developing students’ content knowledge, their capacity in doing science and their epistemic awareness, efforts have been made to engage students in an applied use of different kinds of knowledge through a wide range of scientific practices. Implemented in this way, modelling as a scientific practice holds the potential to facilitate students’ development of subject-specific knowledge, modelling practices, and meta-knowledge about MoMo by intertwining all three elements in an applied use targeted at a specific question to be answered or task to be solved (Nielsen & Nielsen, 2019).

Along the same lines, the trend towards scientific practice playing an increasingly prominent role in science education curricula is often embedded in a wider shift towards competence-oriented curricula (Ananiadou & Claro, 2009). It is furthermore argued that the dominant enactment of scientific inquiry in classrooms as a self-contained step-by-step procedure, combined with a teaching practice focused on content knowledge, no longer corresponds to the way science is practiced (Passmore, Gouvea & Giere, 2014).

In this light, we need to reconsider how models are positioned and used in the science classroom. Too often, models make their way into the science classroom in ways that focus entirely on their representational nature (what they are of) without any reference to how they can be used as tools for exploration, task- or problem-solving or generating knowledge (what they are for) (Gouvea & Passmore, 2017). Not only the product but also the process thus ought to be a central part of a teaching and assessment practice aiming to develop students’ competences in modelling as a scientific practice (Nicolaou & Constantinou, 2014).

The Danish science curriculum

As part of a new school reform, a new national science curriculum for lower secondary education (grades 7 to 9) was initiated in Denmark in 2015-2016. One significant change relates to the teaching approach. In the former, curriculum knowledge and skills held a dominant position and were mainly approached as two different aspects of learning. In contrast, the reformed curriculum was guided by four main competences (modelling, inquiry, communication, and ‘perspectivation’) that are transversal to the three science disciplines – Physics/Chemistry, Geography and Biology. Aside from the introduction of a competence-oriented approach to teaching, the most striking curriculum change was the prominent role given to MoMo in the revised curriculum.

The new curriculum contains significant changes related to the characteristics of what and how to address models in teaching. Most importantly, there is a change from largely approaching models as a product of knowledge used for visualization, simplification and explanation to a more process-oriented approach focusing on students’ application of different elements of knowledge to different aspects of modelling practices, i.e., comparing and selecting between multiple models as well as designing, revising and evaluating models. Along the same line, the revised curriculum also relates the nature of models to their function in scientific inquiry, such as adjustability to fit different purposes.

The new curriculum also reflects a shift from a hegemonic view of the scientific method (i.e. field and laboratory investigations as the main inquiry practice) to a broader view involving modelling (Nielsen, 2018).
It is notable, however, that in the curriculum’s overview of the four competences the process-oriented approach is mainly related to inquiry. In this compulsory overview, modelling is solely defined as “applying and evaluating models”. In contrast, inquiry is defined as “designing, conducting and evaluating investigations”. In fact, the process-oriented approach to MoMo is only reflected in the curriculum guidelines. Identifying the process-oriented aspects likewise requires an understanding of MoMo as a scientific practice as well as a good deal of time.

It is to be expected that the introduction of so many major changes will be a daunting task for teachers. Indeed, recent science education research has demonstrated that the way teachers understand and enact MoMo in their teaching and their rationale is a primary factor in whether the potential benefits of working with MoMo will be realized or not (Krell & Krüger, 2016; Miller & Kastens, 2018; Nielsen & Nielsen, 2021). Teachers are furthermore challenged with how to make the concept of competence operational for teaching and assessment—a challenge that seems to be a general trend in the shift towards a competence-oriented curriculum (Dolin, Nielsen & Tidemand, 2017).

The purpose of this study is to analyse the alignment between the intentions and arguments for integrating MoMo into science education, on the one hand, and teachers’ understanding, practices and rationales for integrating MoMo into their teaching practice, on the other.

Our research questions guiding this study were consequently:

RQ 1: To what extent do science teachers’ perceived practices and rationales for integrating MoMo in their teaching align with modelling as a scientific process?
RQ 2: How do science teachers experience their efforts to enact the MoMo intentions in the revised curriculum?

THEORETICAL FRAMEWORK

In 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 or a system (Gilbert & Justi, 2016). The model could appear in a variety of forms such as: symbols, physical models in 3D, animations, analogies, interactive simulations, kinaesthetic models, drawings or diagrams.

While the noun ‘model’ could be perceived as the product of a scientific process, the verb ‘modelling’ can be viewed as the conducting of a scientific process or practice 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 (Baek & Schwarz, 2015).

Indeed, the linking between data and model is a key aspect of modelling and therefore ought to play a central role in teaching for modelling competence (Auning & Nielsen, 2020; Schwarz & White, 2005), for instance, by providing students with opportunities to develop, evaluate and revise models based on their own or others’ empirical data. The iterative cycles of designing, evaluating and revising models are likewise an important part of fostering students’ modelling competence (Passmore, Stewart & Cartier, 2009). The iterative cycles combined with empirical data also add to students’ awareness of modelling as a knowledge-generating scientific method (Baek & Schwarz, 2015).

In our previous work, we argued that the different aspects of modelling practice provide an action dimension to teaching around students’ engagement with the modelling process and therefore ought to be at the heart of a competence-oriented approach to MoMo (Nielsen & Nielsen, 2019). We suggested a range of different aspects of modelling practice. 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. In the same work, we emphasized that using models descriptively as a means of describing, explaining or communicating a phenomenon is a part of but not sufficient when aiming to develop students’ modelling competence. Competence-oriented teaching ought to include using models predictively as tools for inquiry, assessing scenarios based on different actions or situations, problem-solving, sense-making or as hypothetical entities representing different ideas of the referent.

Inspired by Gouvea & Passmore (2017) “Models of versus models for” approach, we would claim that a competence-oriented teaching ought to include a “Models for” approach. A “Models of” approach, primarily treating models as representations of what is known, is not sufficient when teaching for modelling competence. This kind of teaching also ought to position MoMo as tools for inquiry, sense-making and knowledge generation.

In sum, when teaching to foster students’ competence in modelling as a scientific process, one ought to include different aspects of modelling practices with special attention to: (1) the predictive function of models; (2) the entire process of designing, evaluating and revising models; and (3) the link between empirical data and MoMo. Furthermore, the potential for using MoMo purposely for solving problems, tasks and answering questions (in different situations) should play a dominant role in teaching for modelling competence. The emphasis on how models are developed and used for a specific purpose likewise calls for a “Models for” teaching approach.

RESEARCH METHODS
To answer the research questions, a multiple methods qualitative design was chosen. The main methods used for data production were (a) explorative semi-structured interviews (Kvale, 2006) with three different teacher-pairs, framed as reflection sessions related to their existing teaching, and (b) talk-in-interaction from planning workshops sessions of the teacher-pairs related to their forthcoming teaching. One reflection and three workshop sessions were conducted with one teacher-pair at three different schools during fall 2016 and spring 2017. Moreover, the descriptions of the teaching activities developed during the workshops were collected and used as data.

The teachers participating were employed at three schools located in urban and suburban areas of the Capital Region of Denmark. The teachers had different levels of teaching experience (ranging from two to 20+ years). All teachers taught Physics/Chemistry, all except one taught Biology, and three taught Geography as well. In the data presentations, each teacher was given an individual code in the form of a letter (A, B, C). In addition, the teachers were identified by school, by a number (1 to 3). E3 only participated in the reflection session and one workshop.

The interviews were designed as reflection sessions. To facilitate the discussion and teachers’ reflection, the interviewer placed a range of cards with pre-formulated statements on a table and these were regularly picked up during the sessions. The statements were formulated as suggestions on how and why to address MoMo and engage students in different kinds of modelling practices in their teaching. The teachers were asked to elaborate on how the statements reflected the use and function of MoMo 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.

The transcribed interviews were analysed using Braun and Clarke’s (2006) inductive six-phase tool for thematic analysis with the support of NVivo software. The aim of the analysis was to find crosscutting, consistent and prominent themes that emerged from the teachers’ discussions. First, the transcripts were re-read several times together with the posters to gain a familiarity with the data. During the reading, ideas for coding and interesting features in the data were noted. Examples of interesting
features were the significant differences in the way the different participating teachers approached multiple models. In order to structure the analysis, each teacher’s dialog was first divided into sequences of turns depending on which of the modelling practices (i.e. describing, explaining, communicating, 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.

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. 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 to measure 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, minimize overlap between themes and ensure that there was enough data to support the themes. When analysing the talk-in-interactions from the workshops, we used the themes found in the interview sessions as the “analytic lens”. In general, the density of information related to the research questions was higher in the reflection sessions than the workshop sessions. The largest part of the data supporting our findings hence derives from the reflection sections.

FINDINGS AND DISCUSSION

Our findings are ordered into the three main themes that emerged from the thematic analysis of teachers’ talk-in-interaction: (1) MoMo as the product of a scientific process rather than part of a scientific process; (2) Multiple approaches to teachers' progress and confidence in enacting MoMo as a scientific process; and (3) Experiments reflecting elements of a scientific process.

MoMo as the product of a scientific process rather than part of a scientific process

Teachers’ perceived ways of engaging students in MoMo activities reflected an approach by which MoMo activities were mainly treated as the product of a scientific process rather than part of a scientific process. This finding manifested itself in several ways.

First, our data showed that the most common MoMo practice for all teachers was students’ use of models for the more product-oriented aspects of practices also identified in the former curriculum (i.e. for description, communication and explanation). The following quote is illustrative of the way the teachers generally perceived their enacting of MoMo:

“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).

Or in the words of another teacher:

“That’s what we use models for - communicating complicated content ... it’s easier to show it in a model” (A2).

In contrast, the teachers were less frequently enacting the new more process-oriented practices (i.e. evaluating, designing, revising, comparing, predicting). 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).

The practice of revising models similarly had little or no role in all 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).

Our data thus indicate a minor use of some of the central aspects that ought to be included in an enacting of modelling as a scientific process (Baek & Schwarz, 2015). In line with prior research (e.g. Khan, 2011), the prevalence of the more product-oriented practices indicate that MoMo were mainly enacted as a learning and teaching tool to facilitate students’ learning of the subject-specific content knowledge embedded in the model. Or, in other words, our data suggest a teaching practice mainly treating MoMo as a product of knowledge to be learned and not as a part of a scientific process used for predicting or knowledge-generating.

Second, when process-oriented aspects of MoMo practice were enacted in classrooms, they were 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 small stop-motion-movie with plasticine showing the protein synthesis [...] in this way they will build a dynamic model” (D1).

Our data thus suggest that the teachers are mainly implementing the practice of design as the construction of different kinds of models based on established models or knowledge. This finding is also reflected in the examples that emerged from the workshop sessions in Table 1.

Table 1: Examples of different aspects of modelling practices developed by five teachers at three specific schools during lesson planning workshops. Each teacher and school are given an individual code in the form of a letter and a number, respectively. Please note that even though most of the examples cover more than one aspect, they are only listed once in the table, and some activities enacted by more than one

<table>
<thead>
<tr>
<th>Aspects of modelling practices</th>
<th>Examples of students’ engagement with different aspects of modelling practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explaining, describing,</td>
<td>Select a model from a predefined collection of visual 2D models of a nitrogen</td>
</tr>
<tr>
<td>communicating</td>
<td>cycle and add own explanation to the arrows in the model (B2)</td>
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<td></td>
<td>Explain the six key elements in a selected nitrogen model with the correct</td>
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<td></td>
<td>terminology (C1)</td>
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<tr>
<td></td>
<td>Explain or describe the content knowledge represented in their own or book</td>
</tr>
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<td></td>
<td>models for classmates (A2, B2, C1, D1, F1)</td>
</tr>
<tr>
<td>Predicting</td>
<td>Predict the outcome of a DNA frame-shift mutation on the sequence of amino</td>
</tr>
<tr>
<td></td>
<td>acids in proteins (D1)</td>
</tr>
<tr>
<td></td>
<td>Predict a change over time in CO$_2$ concentration in a closed ‘micro world’</td>
</tr>
<tr>
<td></td>
<td>bowl with soil and an apple representing the process of respiration (A1)</td>
</tr>
</tbody>
</table>
As can be seen, the participating teachers had a preference for asking students to design models based on established knowledge (e.g. text or 2D illustrations from books, teaching portals, YouTube). Students’ design of models is thus reduced to replicating what is already known or simply changing the kind of model. According to Schwarz and White (2005), one element of modelling is that of developing models by embedding key aspects of theory and data into the model. From this perspective, teaching without linking students’ empirical data and findings to model design would not give a full picture of modelling as a scientific process. Indeed, this kind of teaching would not only limit 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.

### Designing

<table>
<thead>
<tr>
<th>Designing based on own data</th>
<th>Plot on a graph the temperature changes in two containers (one with CO₂ added) as light shines on them to model the Greenhouse Effect based on data logger measurements (A2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluating</td>
<td>Evaluation of 3D models (composting bowl and bottle garden) and 2D illustrations representing different aspects of the carbon cycle. Evaluation based on what kind of answers the model may or may not provide (F3)</td>
</tr>
<tr>
<td></td>
<td>Come up with suggestion on how to improve preselected 2D illustrations based on students’ own criteria mainly focusing on design and power of communication (A2)</td>
</tr>
<tr>
<td>Revising</td>
<td>Add more details or elements to 2D illustrations from the textbook (A2)</td>
</tr>
<tr>
<td>Comparing</td>
<td>Denote an adequate heading for the specific content in eight predefined visual 2D models of a carbon cycle (A2)</td>
</tr>
<tr>
<td>Selecting</td>
<td>Select a ‘model experiment’ from a preselected list that illustrates an arrow in an overall 2D nitrogen cycle model (B2)</td>
</tr>
</tbody>
</table>

*teacher are merged.*
Our data also shows that not only established models were evaluated but also models designed by the students. This finding is exemplified in the words of one teacher in relation to assessing students’ own nitrogen cycle models:

“In fact, what I find difficult is coming up with criteria for evaluating... making the criteria specific to the concrete [nitrogen] cycle” (B2).

It is worth noting that the above quote is illustrative of the way in which most of the teachers give importance to assessing students’ modelling capability in their teaching. More concretely, teachers’ evaluation of students’ ability to use MoMo was mainly related to students’ products - the models - and not to students’ abilities in modelling as a scientific process. This product-oriented approach to modelling was also reflected in teachers’ perceived prospects for enacting students’ revision of their own models:

“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).

Our data therefore suggest a product-oriented approach to the evaluation of students’ design and revision of their models. Indeed, activities in which students create a model based on their own predictions about the referent and then compare, evaluate and revise the model with observations in the real world (or design an investigation to test their ideas about the target) would arguably be much more process-oriented (Passmore, Stewart & Cartier, 2009; Windschitl, Thompson & Braaten, 2008).

Third, our data suggest that the nature of MoMo in the teachers’ practice is treated as a knowledge product representing part of the ‘real world’. Indeed, teachers mainly emphasized the nature of models as simplifications of, and artefacts for showing or explaining, the real world:

“We use models to make a visualization of the abstract stuff from the real world” (C1).

Or in the words of another teacher:

“It’s necessary to simplify complex issue from the real world... like when we are working with the nitrogen cycle [...] then we need models” (D1).

In contrast, the nature of models related to the process (i.e. tentative, accessible, hypothetical entities representing different ideas of the target) only held a minor place in teacher practice. This point is expressed by a 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).

Our data thus resonate well with former research which found that MoMo in teaching is largely positioned and used in ways that focus entirely on their representational nature without any reference to how they can be used as tools for inquiry, task or problem-solving or generating of knowledge (Gouvea & Passmore, 2017; Krell & Krüger, 2016; Miller & Kastens, 2018).

Fourth, the iterative and dynamic process of designing, evaluating and revising models based on students’ own ideas about the target, inquiries or data played only a minor role in most teachers’ practices. In particular, the process of revising models as described in the new curriculum (e.g. testing a model against reality, revising models to fit the target) had little or no role in any of the teachers’ practice. For example, one teacher asserted that:

“I never do that...I don’t identify that practice [revision] at all in my teaching” (E3).

Or in the words of another teacher: “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).
It is worth noting, that the above quote illustrates a very restricted way of understanding the practice of “revision”. Indeed, the iterative cycles of designing, evaluating, and revising models were not perceived as an important part of enacting MoMo as a scientific process.

The participating teachers’ minimal use of revision is also in line with previous findings (Khan, 2011; Krell & Krüger, 2016). As argued by Campbell and Oh (2015), modelling without revision limits the prospects of affording 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 (Passmore, Gouvea & Giere, 2014).

Fifth, our data suggest that the use of models related to students’ inquiries was largely perceived as a tool for illustrating the result of students’ inquiries or contextualizing an experiment in a pre-designed model. The first point is illustrated in the following quote:

“The students love this kind of experiment where it is possible to draw a graph […] in fact I select experiments based on the prospects for students to illustrate the result by means of a graph in their lab reports” (D1).

The latter point is exemplified in this extract related to if, and in what way, the students were crafting models based on their own experiments:

D1: “Well I did it a little bit the other way around. Found this water density experiment to illustrate a part of the [i.e. a 2D] Gulf Stream model…”

C1: “Yes […] how is the experiment related to the model … where are we in the model?”

In this way, the inquiry aspect of modelling was reduced to a descriptive tool for illustrating or depicting a part of an already realized investigation. As argued by Passmore, Gouvea and Giere (2014), modelling as a scientific process requires more than finding patterns in data or determining relationships between variables. Indeed, a more predictive and process-oriented approach would be to ask the student to design a hypothesis model of a relationship between two variables and then test their idea by investigating the target.

Finally, our data suggest that some teachers hold a rather implicit distinction between a model and the process of modelling. This point is also illustrated in this quote:

“In this teaching unit we have decided that when working with modelling as a competence, students needed to include a model […] and when working with inquiry as a competence, they needed to include an investigation – you know a kind of experiment […] so we separated the two competences” (C1).

Our data thus suggest that, for some teachers, modelling was perceived as detached from students’ own inquiry work. In other words, our findings suggest that some teachers do not distinguish between a model and the process of modelling. The teachers’ shortcomings in perceiving modelling as a scientific practice equivalent to inquiry might partly derive from the overview curriculum description which solely defines modelling as “applying and evaluating models”, while the same overview defines inquiry as “designing, conducting and evaluating investigations”.

In sum, the data indicate that, in these teachers’ understanding and practice, MoMo was mainly treated as the product of a scientific process rather than as part of a scientific process. In other words, modelling was mainly perceived and treated as a model of something and not as an inquiry process for predicting or building explanatory knowledge. Indeed, a “models of” approach is not sufficient in a teaching that is aimed at developing students’ reflective agency in modelling (Gouvea & Passmore, 2017; Nicolaou & Constantinou, 2014). From this perspective, the participating teachers’ approach to MoMo reflects the former curriculum’s intentions (as well as former approaches to science education in general) by focusing on the content knowledge of the models without addressing the processes that led to the knowledge embedded in the model. We will now turn to our findings on how the teachers experienced their efforts to enact the reformed curriculum.
Multiple approaches to teachers’ progress and confidence in enacting MoMo as a scientific process

As argued above, the teachers’ narratives and teaching examples largely reflected aspects of practices found in the former curriculum. Furthermore, all the teachers perceived it as quite a straightforward task to enact these more product-oriented aspects of practices. Our data further suggest a quite uniform and explicit enactment of these practices. In relation to teachers’ enactment of the newer more process-oriented practices, however, our data painted a more diverse picture.

Most teachers found it very challenging to enact the new more process-oriented aspect of MoMo. In line with previous findings (Khan, 2011; Krell & Krüger, 2016), revision in particular seems to challenge most teachers. Our data indicate that this challenge was not only related to a perceived lack of competence but also to a restricted understanding of how to operationalize revision. This point is exemplified in 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).

Indeed, the above quotes illustrate a very restricted understanding of the practice of revision since these teachers’ perceptions of enacting revision was in terms of revising established models in textbooks.

While all teachers were challenged by enacting revision as part of a scientific process, our data showed multiple approaches to the way in which a wide range of other aspects of MoMo practice were perceived with respect to progress, manageability and teachers’ confidence in enacting these aspects.

For instance, some of the more experienced teachers did develop activities with the newer more process-oriented modelling practices, such as engaging students in comparing and evaluating multiple models. For these teachers, these activities were perceived as an established, explicit, reflective, purposeful, and highly-valued practice. This point is exemplified by the following quote:

“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).

These teachers, over time, had furthermore experienced a ripple effect on their subsequent teaching:

“We both did it [asked our students to compare and evaluate multiple models] as a course in these classes... and now we remind them of what we did in this course every time we work with something that has to do with models [...] I’m also more skilled at using models nowadays...it has changed over time” (A2). Or, in the words of the same teacher: “Did you see the tree of life on the wall? My students designed it based on a range of multiple models they found [...] they should make a critical choice [...] and make their own”.

The quotes also indicate an interesting point in teachers’ handling of new aspects to be enacted in their teaching with regard to meaningfulness and willingness. In line with previous research (Nielsen, 2012), our data indicate that it is less of a tall order if the teachers had experienced “salient outcomes” related to students’ engagement or learning. The same point is illustrated with respect to designing models:

“Well I’m really trying to do it more [...] I found out it’s...good for learning...so I’m doing it more and more” (D1).

While some teachers had in this way developed a frequently enacted practice with multiple models, some of the less experienced among them had another approach to integrating this aspect into their teaching with respect to progress and manageability. 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] [...] it’s already hard to get time enough just working with models – and then even with more models at the same time [...] we also need time for inquiry work…that’s important for me” (F3).

Similarly, another teacher considered it only manageable to enact students’ comparison and evaluation of multiple models with a limited number of more advanced students:

“I did it in grade 9 [...] but the class was split in two [...] it could be interesting to do it more... also in lower grades” (E3).

As illustrated above, the more inexperienced teachers not only integrated the process-oriented modelling practices to a far lesser extent but they also felt it was hard to fit it into their existing practice. They also felt less confident in enacting these practices.

Along the same lines, the talk-in-interaction points to how teachers’ own perceived lack of experience influenced their reliance on teaching material:

“Right now I feel more confident in using the examples from the teaching material [...] you know you are building on the work of somebody else .... someone more competent [...] I might try out more when I get more experience” (E3).

Although these teachers perceived it as challenging to integrate some of the new practices into their teaching, they still expressed a willingness to develop these new practices:

“I would like to include revision of models...but I don’t know how [...]” (D1).

This willingness to develop these new practices was also reflected in the modelling activities that the teachers developed for their forthcoming teaching during the workshops.

Although explaining or describing the content knowledge represented in established models held a dominant position in all teachers' lesson planning, other aspects of modelling practices were also developed by the teachers. Some teachers were planning to enact modelling practices that were not normally part of their teaching: designing (F3, C1) and predicting (A2). One teacher (D1) had also developed and enacted a gesture model that they had been working with for a long time. The same teacher was further planning to transfer her implicit and rather unconscious use of prediction into an explicit teaching activity (D1). Moreover, another teacher (F3) was even planning to enact the aspect of modelling practices (comparing and evaluation) that she perceived as being highly challenging. In the same vein, the more experienced teachers (A2, B2) were developing new student activities based on their valued experience of multiple models (describing suitable headings for different multiple models) or were elaborating on their existing practices with models (designing micro-worlds) or experiments (students working with model experiments). Moreover, some of these modelling activities went beyond a solely descriptive use. The examples are described in more detail in Table 1.

It is notable that the talk-in-interaction about teachers' planning of their forthcoming practice suggested that, if teachers could identify elements in their existing practice that could be developed by extending it with new aspects or making it more explicit, then this was perceived as more relevant and manageable than enacting entirely new aspects of modelling that did not resemble their existing practice (i.e. revision). This point was particularly visible in teachers' teaching examples related to predicting and the way the teachers used their valued experience from laboratory work to develop what they called ‘model experiments’ and ‘table micro-worlds’. Combining teachers’ two valued practices (i.e. using models for explaining and laboratory work) to engage students’ in laboratory work, was perceived as both manageable and meaningful for the teachers.

In sum, most teachers found it very challenging to enact the new more process-oriented aspect of MoMo. While our data thus show critical areas for enacting the intentions of the reformed curriculum, our data also suggest that the teachers are already (albeit to different extents) in the process of...
developing and enacting the new aspects. They are likewise willing to implement a more process-oriented approach to MoMo in their teaching. In line with prior research (Janssen, Westbroek & Doyle, 2014; Nielsen, 2012), our findings indicate that where teachers had experienced “salient outcomes” or could identify elements of the new process-oriented practices in their existing teaching practice, then it aided their enacting of these aspects.

**Experiments reflecting elements of a scientific process**

While teachers’ approach to modelling as a scientific practice was mainly treated as the product of a scientific process rather than part of a scientific process, our data did nonetheless reveal some interesting points with respect to students’ involvement in laboratory work.

In fact, our data suggest that while teachers may not prioritize the scientific process with regard to modelling, they do have another approach to experiments. Not only was this kind of activity enacted and perceived as an important part of their teaching but the process, such as crafting hypotheses, students posing their own questions, trying things out and students designing their own experiments, played a dominant role in all the participating teachers’ narratives related to experiments. This point is illustrated in the following quote:

“I prefer that the students are not given the answers in the beginning [when working with experiments], let them try things out…and say oh wow...that’s cool we did not expect it [a solvent] would dissolve this amount. It would be so great to get rid of students using these recipe experiments from Prisma [a book system]” (E3).

Or, in the words of another teacher in relation to experiments:

“They need to make a hypothesis, pose questions […] they need to practice their skills [i.e. laboratory]” (B2).

It is also notable that the first quote indicates a willingness to change a teaching practice, reflecting what Passmore, Gouvea and Giere (2014) denote a “self-contained step-by-step procedure” of scientific inquiry not reflecting an authentic enactment of scientific inquiry in the classroom.

Indeed, teachers’ narratives indicate a teaching practice that addresses predicting, conveyed as students’ crafting of hypotheses, as an important aspect of enacting experiments:

“In grade 8 we have been working a great deal with students finding experiments, crafting hypotheses, and putting up an argument for it, right?” (F1).

Students’ reflections related to the process were also considered an important aspect:

“When we say that the students do an experiment, we don’t mean a recipe...we would like them to think for themselves - its important they know what they are doing” (A2).

Our data therefore implies that the teachers (albeit to different degrees) were undertaking a less descriptive and more process-oriented enactment of experiments compared to how students were engaged in modelling. For some teachers, the main purpose of experiments was in fact related to the process (e.g. crafting hypotheses, sources of error) and students’ skills in this regard.

In contrast to the teachers’ enactment of MoMo, students’ engagement with experiments was neither guided nor oriented towards theoretical content knowledge. This point is illustrated in a talk-in-interaction between two teachers responding to the relevance of students using the theoretical knowledge embedded in models to inform their generation of hypotheses:

A2: “Not really […] they should just be allowed to wonder and write some questions and guess a little. No need to work theoretically and engage in all sorts of models at this point.”

B2: “It may come in the second stage.”

A2: “It can come afterwards […] So I don’t consider it [using model] as part of crafting a hypothesis.”
In sum, teachers’ approaches to experiments were more process-oriented and included more elements reflecting a scientific process compared to teachers’ enacting of MoMo. There was likewise a willingness to enact a more authentic approach to inquiry related to students’ engagement with experiments.

CONCLUSION AND IMPLICATIONS
Despite teachers’ multiple experiences, they were all challenged by how to enact modelling as a scientific process. While our findings thus show a lack of alignment between teachers’ practice and the intentions of the reformed curriculum, the findings also suggest that the teachers are already (albeit to different extents) in the process of developing and enacting a more process-oriented approach to MoMo.

Whereas our findings show critical areas for the continued development of teachers’ practice in realizing the curricular intentions, our results also point to potential actions that could be taken to develop teachers’ possibilities in this regard. Based on prior research (e.g. Janssen, Westbroek & Doyle, 2014) and our findings, we believe that if teachers could identify experienced and valued elements in their existing practice that could be extended, this would be more manageable as opposed to enacting entirely new aspects of modelling that do not resemble their existing practice at all.

In this light, and inspired by Windschitl, Thompson and Braatens’ (2008) “Model-Based Inquiry” framework, we suggest that teachers’ descriptive approach to MoMo, as well as their restricted use of modelling as scientific practice, could be expanded by combining MoMo with teachers’ valued and well-established practice around inquiry related to students’ experiments.

This could, for instance, be undertaken through students:
- crafting testable predictions based on established models representing core causal explanations;
- empirically testing sub-processes in models against own data from observations or experiments, field or laboratory observations;
- crafting testable predictions based on models representing students’ own ideas about a phenomenon;
- evaluating and revising their own tentative 2D models based on empirical data;
- evaluating and revising their own ‘table models’ based on new theoretical considerations, advanced learning or new purposes;
- considering what and how to represent their data using different types of models; and
- designing, comparing and evaluating each other’s models representing the same target (i.e. a forest ecosystem) but based on different kinds of data (i.e. temperature or humidity measurements), data collecting strategies (i.e. number of samples, different techniques for random sampling), equipment for data collecting (i.e. datalogger or manual temperature measurement) or different tasks to be solved (i.e. testing variation in daily temperatures over 24 hours or testing the relationship between humidity and temperature).

Such efforts would not only add to a more predictive and process-oriented approach to MoMo but would also raise awareness among students of how models are used as an inquiry tool in science to make sense of the world. In addition, this kind of teaching would contribute to students’ understanding of the interaction between subject-specific knowledge, data and models. Furthermore, 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 (Baek & Schwarz, 2015). Indeed, our suggested approach has the potential to facilitate students’ development of subject-specific knowledge, modelling practices, and meta-knowledge about MoMo by intertwining all three elements in an applied use targeted at a specific task (Nielsen & Nielsen, 2021).
LIMITATIONS
One important limitation of the study is that it is based on teachers’ own narratives and perceptions of their own teaching. We do not know if these narratives portray a ‘true’ picture of these teachers’ practice. However, we do believe that the framing of the sessions as reflections and workshop sessions produced narratives very close to teachers’ actual practice. In this light, and despite the above-mentioned limitations, we still think our study allows us to identify some important patterns related to Danish science teachers’ practices and prospects for realizing the intentions in the revised curriculum.

ACKNOWLEDGEMENTS
We wish to thank the participating teachers for donating their time and giving us the opportunity to add to our understanding of their teaching and rationale in this regard. We also thank Birgitte Lund Nielsen for her valuable comments and suggestions for improving this article.

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