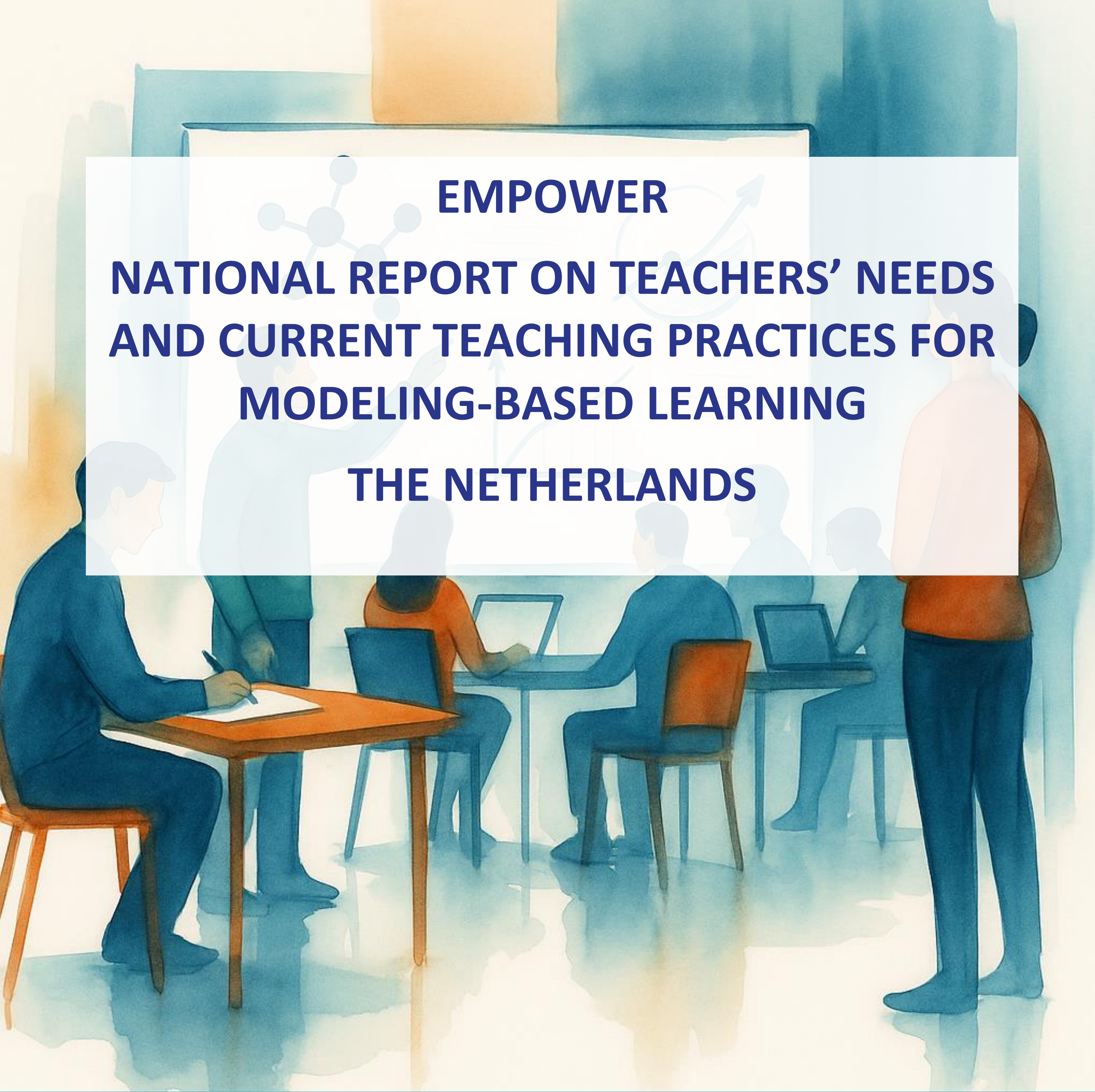

# EMPOWER

# NATIONAL REPORT ON TEACHERS' NEEDS AND CURRENT TEACHING PRACTICES FOR MODELING-BASED LEARNING

# THE NETHERLANDS

2026

EMPOWER

Empowering Teachers for Science Learning Through Modelling-Based Approaches

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# Erasmus+ Project EMPOWER

## EMPOWERING TEACHERS FOR SCIENCE LEARNING THROUGH MODELLING-BASED APPROACHES

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# 1 Introduction

This report is situated within the Dutch educational context, with a primary focus on lower secondary science education. In the Netherlands, Natural Sciences in lower secondary education are organised within the broader curriculum domain *Mens en Natuur (Humans and Nature)*, where biology, physics, chemistry, and earth science are often taught in an integrated and coherent manner. This curriculum structure is currently undergoing renewal, with an increasing emphasis on conceptual understanding, scientific literacy, and the development of scientific practices such as reasoning, inquiry, and modelling.

Within this context, Modelling-based Learning (MbL) is relevant because it reflects the central role of models in scientific knowledge construction and supports students in engaging with science as an explanatory and inquiry-driven activity. It aligns with current curriculum aims that emphasise scientific literacy, systems thinking, and the use of representations to understand complex phenomena. MbL contributes to these aims by enabling students to construct, use, and refine models to develop and test explanations of scientific phenomena, thereby strengthening both conceptual understanding and scientific reasoning. It can be embedded in classroom practice through learning activities in which students work with and evaluate models as part of scientific inquiry.

However, the practical implementation of modelling in everyday classroom practice remains challenging. Although modelling is recognised as an important scientific practice, it is often not yet systematically embedded in teaching materials or lesson design. For this reason, it is important to better understand what makes modelling difficult in practice and how it is currently being implemented. It is therefore valuable to ask teachers, textbook editors, and other relevant Dutch stakeholders what they do and do not do with modelling-based approaches, what challenges they experience, and what they perceive as helpful in supporting its implementation. Examining these perspectives is essential for identifying current strengths, challenges, and priorities for further development in the Dutch context.

# 2 Educational Context

The Dutch educational context is characterised by a decentralised, standards-guided system, in which the national curriculum sets general learning goals while schools retain considerable autonomy in how these goals are interpreted and implemented in classroom practice. This creates a context in which the translation of curriculum intentions into teaching varies across schools and subjects, including science education.
Within this system, multiple stakeholder groups influence how MbL is shaped and enacted. Curriculum developers, test developers, and educational researchers play an important role

in defining how modelling is represented in national standards, assessment frameworks, and educational guidance. Their decisions influence the extent to which modelling is emphasised, how it is conceptualised, and how visible it becomes in both curriculum materials and assessment practices.

At the same time, teachers have substantial autonomy in how they design and enact science lessons, meaning that their practices strongly shape how MbL is realised in classrooms. However, this teacher-level implementation is influenced by both teacher education and available teaching materials. Teacher education does not yet consistently provide explicit preparation for modelling as a structured pedagogical approach, which contributes to variation in how teachers understand and apply MbL. In addition, textbook publishers play a significant role, as many teachers rely heavily on textbooks and associated materials. These resources often shape how modelling is introduced and supported, with modelling frequently appearing implicitly through diagrams and explanations rather than as an explicit, iterative process of model construction, testing, and refinement.

Overall, the implementation of modelling in Dutch science education is shaped by the interaction between curriculum-level decisions, assessment practices, teacher autonomy, teacher preparation, and the influence of textbook materials, resulting in variation in how MbL is understood and enacted in practice.

# 3 Method

In the Netherlands, four focus groups were conducted and hosted by Utrecht University and Radboud University. Specifically, two focus groups were conducted with lower secondary chemistry, physics, and biology teachers, and the other two focus groups included stakeholders from curriculum development, assessment (test development), teacher education, educational research, and textbook publishing. The participants were recruited through professional networks on a voluntary basis. In total, seven teachers participated across the two teacher focus groups, and seven stakeholders participated across the two stakeholder focus groups.

The focus group discussions were conducted online via Teams, with a duration of approximately 60 minutes per session. The discussions followed a semi-structured protocol designed to elicit participants' views and experiences of MbL in science education across different levels of the system. Topics included participants' understanding of models, modelling, and MbL; the role of modelling in science education; and how modelling is currently addressed in curricula, textbooks, teacher education, and classroom practice. In addition, the discussions explored perceived challenges, available resources, and support needs for strengthening the implementation of MbL. While the protocol structured the sessions, the discussions remained open to allow participants to elaborate freely and engage in interaction with one another.

All sessions were audio-recorded and subsequently transcribed. The data were anonymised to ensure confidentiality. Data analysis focused on identifying recurring themes, patterns, and differences across the focus groups, with particular attention to how Modelling-based Learning (MbL) is understood and enacted across different stakeholder perspectives. Data used in this report was translated to English.

# 4 Findings

## 4.1 Knowledge

### Learning Goals

<u>Critical thinking:</u> Teachers mentioned that they want their students to become critical citizens. They want them to be able to critically look at the world and information, especially online information, and give them the ability to ponder whether their own logic is correct. Other stakeholders echo this, highlighting mostly that students should understand the world around them, apply knowledge, and form an opinion on complex topic: “I think it goes beyond just understanding, because sometimes it is about being able to form an opinion and relate to certain issues, maybe even exploring action perspectives.” Furthermore, both teachers and stakeholder mention scientific literacy. Teachers link critical thinking to scientific reasoning. Scientific reasoning is mentioned mostly in the form of systematically understanding how the world works. One teacher stated that modelling can help develop scientific reasoning, because it helps students to be able to validate and test everything around them. Another teacher mentioned that they want students to become aware that physics is not just about applying formulas, it is about learning how these formulas come about and where they belong to, signaling again that models and modelling can aid students’ scientific understanding. One stakeholder said: “You have to know how science works, that is more than just understanding how the world works, it also encompasses how that knowledge came into being.” Stakeholders further highlighted the importance of a broad approach to science education, recognising its value for both STEM preparation among all students: “I think it is important that students who choose the STEM subjects and want to pursue a career in them get an education that provides them enough immersion and mathematical immersion to be able to do that. On the other hand, I think it’s also very important that students that do not choose STEM subjects and only get the mandatory 3 years of them know something about the world around them. They should have safety over their own metacognition, understand the news, develop citizenship.”

Social responsibility/awareness: Several teachers mentioned social responsibility as a learning goal. Two teachers mentioned that they teach their students about socio-scientific phenomena, such as sexual identity, sustainability, and nuclear power plants, phenomena that add a layer of social responsibility MbL. Another teacher stressed the importance of making their students aware of the social aspect of science in general. They mentioned that scientific knowledge is not constructed in solitude, but that theories are jointly constructed: “We as a society build knowledge.”

Mental models: One teacher mentioned that they want their students to be aware of and understand how their own brain works. They mentioned that students are often taught to perceive learning as a process of memorization, which they argued is an inaccurate understanding of how learning occurs: “We, but most important students, need to understand that our brains do not learn from repeating lines… That is what students kind of teach themselves, you know, they memorize lines and concepts word for word, but that is obviously not how our brains work, at least not for me personally.” Another teacher echoed this by saying: “It is also about creating that concept in your mind. Making and manipulating a model can help learn how to do that.”

Practical skills: One stakeholder that focuses more on lower levels of secondary education highlighted the importance of practical skills in STEM subjects: “At the end of the day, physics is a practical subject. An exam is a lot of text and maybe drawing some lines, but at the end you also want them to enter the world and know how to use a multimeter for example.”

### Model definition

Nature of models: Most teachers and stakeholders agreed that they view models as representations of reality. Some mentioned that they view models as simplified versions of reality by only depicting certain aspects of a model. One teacher mentioned that models can also be complex, however, these complex models are usually built upon simpler versions of that model, again highlighting simplification as an aspect of models. An interesting conversation unfolded in one of the stakeholders focus groups, where two participants discussed what constitutes as a model after one participant mentioned how they viewed a formula as a model. The other participant disagreed, saying: “I would like to say that the laws of Newton, are laws. And those off course have limitations. But when I am using them in a physical situation, then I modelling. Then I am making a model using the laws of Newton.” The other participant responded with a critical thought, expressing their view on the difference between a model and a law: “You could also reason it the other way around, I would say. So Newton thought at some point of its law, he made a model, and at some point over time we made it a law. We see that under certain circumstances, it just always works. The model gained a different status, but for me, the law used to be a model.” This conversation shows the different perspectives participants take on the nature of a model.

Purpose of models: A clear consensus among almost all participants was that a model can be a representation of reality, however, it should also have purpose. The purpose that was mostly mentioned was understanding. One teacher highlighted this by suggesting that an analogy is related to a model, but an analogy is not a model itself, because a model should have the purpose of making you understand “what is going on.” A stakeholder also mentioned: “It depends on the function, what [name] mentioned, models can have different purposes, but it is still a model in my opinion.” The other purpose that was mentioned was prediction. Several teachers and stakeholders agreed that in addition to understanding, models can grant one the ability to predict what can happen when hypothetically changing variables in the model.

Multiple models: One teacher mentioned that they thought that “a model must ensure that you can understand something on a variable by adjusting another variable.” Another teacher echoed this but nuanced it by saying that there can be different types of models: “I think I feel there are different types, so you have models where you put variables and factors in and from which you get certain predictions, so those you use to calculate something or work out a certain future outcome of a process. Those types of input-output situations, and we do have those in biology, but say the classical meaning of the word model in biology, that is off course something like a representation of a heart” The knowledge of multiple models is further shown by another teacher, who mentioned that multiple models can depict the same phenomenon in different ways. They mentioned that visually, the same aspect of the phenomenon can also be depicted differently. This is common in Physics, as they often work with graphs and formulas. Some stakeholders agreed with this. One mentioned how “in chemistry, we all know the structural formulas. Those are in fact also models, so in that sense I agree with [name] and for the rest, I think for example block diagrams for factories, for me those are also models.” Another stakeholder said: “I think there are different types of models and different ways of modelling,” which shows their knowledge on multiple models.

### Modelling definition

Testing and changing models: There was a consensus among participants that modelling is a dynamic process in which you aim to understand the world. Some teachers mentioned how they view modelling as the investigation of the relations between two or more variables. A stakeholder echoed this by stating their view on the practices of scientists: “They build models and use them to generate hypotheses that they then test in experiments.” Another stakeholder showed their knowledge on testing and changing models by saying: “I think that it is not just building and making a model, but using the model and refining it. Tinkering with it, if you change this variable, what happens and so on.” Often, explanation or prediction is mentioned as the purpose of modelling, just like it was for models. One teacher mentioned how modelling requires active involvement through actively writing things down and drawing connections. Modelling is seen to have a cognitive component. Many teachers also view the modelling process as cyclical. One stakeholder mentioned their view on the importance of creativity in the process of modelling: ”for me, the focus is really on the creative practice, the creation of the model. […] But it becomes interesting when models can also bring you new ideas. They bring you further than just explaining things. Models need to also bring new testable hypotheses.” Their perspective shows their knowledge on the regenerative nature of modelling. In general, many participants mentioned that they think modelling is the iterative process of constantly testing and changing models.

<u>Social aspect:</u> One teacher mentioned how they view modelling as a social practice within the science community. They explained how modelling involves collaboration with other scientists as they aim to confirm, adapt, or disprove your built model when publishing.

<u>Boundary work:</u> Among the teachers, there was discussion on what constitutes modelling. Teachers agreed that not every process involving a model could be considered modelling, but discrepancies between their definition of what constitutes as modelling could be found here. One teacher mentioned how they viewed the use of a model as modelling a specific situation. Another teacher disagreed, giving the example of using a formula. They did not consider using a formula as modelling, while designing could be seen as a form of modelling. Another interesting example of this is when a biology teacher made this comment: “With modelling I think of something more narrow, I think of simulation models or more mathematical models, always containing something mathematical like you mentioned [name], having an independent variable that can change and that in time or equilibrium or whatever. So a few variables that go in and a few numbers that come out that have to be calculated, for me that is what I associate with it.” They viewed modelling as a mathematical process, involving numbers and input-output calculations, as well as relationships between variables. In response to this, a Physics teacher replied: “and if you think of a model for lungs and how lungs work?” To which the Biology teacher clarified: “Yes we have a construction that can simulate it, we use that as demo material, you can call that a model, yes, but I think that when I am showing that and using that demo, I am not modelling the lungs, for that I would need some sort of figure with all the lung capacities, floss and those kinds of things where you have to calculate… Modelling is an activity. We have a lot of demo models, they are simplified representations of reality that we as teachers show our students to help them understand how our rather abstract bodies work. But if we talk about modelling, I think it is an activity that students perform or something that you build.” This shows that the biology teacher not only differentiated between qualitative and quantitative models, but also made the distinction between modelling and using models as didactical tools. They mentioned how, in Biology, many anatomical models could be used to visualize the human body and gain understanding, but they did not view this as a form of modelling. They claimed that modelling involved building and adapting the model through empirical testing.

## Modelling-based learning definition

Active engagement: When discussing MbL, participants mostly mentioned how students need to be actively engaged in the modelling process. One teacher noted that actively involving students in the process highlights the difference between MbL and traditional education, by stating: “So then you are really learning and making them think, instead of just reading from you book, you are actively participating and using the model as a thinking tool, not and end product.” Another teacher also compared MbL to traditional education, noting that in classical instruction, the model is simply given to the students to apply, while in MbL, students get to build the model themselves and they apply it. This was also said by a stakeholder, who suggested that MbL is about “working with models moreso than conveying knowledge.” This thought was iterated by another participant: “In other situations, you would get the formula given to you, but in model didactics, the students have to reason for it themselves through observations. That I think is also modelling-based learning.” Another teacher also highlighted the importance of having students build the model themselves in class: “I think, regardless of our domain, we have to deal with certain systems. Those have certain structures and elements that work together in a dynamic way. And you can explain them, but I think having students build something simple themselves according to their own logic, being able to test the thing you build based on a piece of theory, that they eventually learn the model that way.” Lastly, one teacher mentioned how they want their students to tread in the footsteps of scientists, by having them perform modelling, as this is a core scientific practice.

Learning the cyclical process: Some teachers also highlighted that students need to understand that modelling is a cyclical process, so learning activities in class need to be designed in a way to either have the students perform multiple cycles or gives them the knowledge that a model is never a finished product. One teacher mentioned how purely constructing a model in class is not enough, using the model and making students think about modification of the model is also necessary.

Interdisciplinarity: One teacher mentioned that MbL is an interdisciplinary form of learning. They mention how in their teaching style, when teaching about a certain phenomenon, they aim to make connections to other subjects regarding the phenomenon. They mention how it helps students think about phenomena in a holistic way. Other stakeholders agreed with this notion. In one focus group, economics was highlighted as a non-science course in which MbL can easily be implemented. One stakeholder, who is also a teacher, said: “My colleauge in Economics does this with her students as well, so I asked her and indeed, they use a lot of the same models we use in Biology.”

## Prior Modelling Knowledge

Personal interest: Most teachers mention that they got their knowledge about models, modelling, and MbL through it being a personal interest. Two teachers mentioned the key memories they have when they had to model or use models themselves, which served as a catalyst for interesting them in the topic.

Active student-centered pedagogy: Some teachers mentioned how they had interest in moving away from traditional education forms into more active, engaging forms of teaching. These teachers encountered modelling because it helped them to move into this direction of teaching.Another teacher with the same vision mentioned how they found a blog suggesting more active learning activities that eventually led them to the discovery of MbL. One teacher mentioned how they wanted their students to be in the role of the scientist and for them to be the focal point of the class instead of the teacher.

Research: Some teachers noted that they acquired knowledge on models, modelling, and MbL through encountering or performing their own research on the topic. One teacher mentioned doing their master thesis on modelling, while another stated that they are a researcher themselves researching computational modelling. Another teacher mentioned how they came into contact with a researcher focusing on modelling.

National curriculum integration: One teacher mentioned becoming interested in modelling when it got introduced into the national learning outcomes, which students would get tested on it on the national final exam.

No mention in teaching education: Interesting to note is that two teachers said that they had not come across the topic of modelling in their teacher education. One teacher explicitly stated that MbL is something they came across themselves and that they did not learn about it in their teaching education. Another echoed this by stating that there was no mention of models in their teaching education. However, one teacher mentioned doing their master thesis on modelling. This shows that the experience teacher get with modelling in their teacher education varies.

## 4.2 Teaching experience

Concept maps: Several different teachers mentioned the use of concept maps. One teacher mentioned the term explicitly, noting that they use a software program for this: “I always use a certain website, but in the simplest form. They can make a nice concept map with it.” Two other teachers do not explicitly mention the term but describe the way they have students practice modelling through making concept maps. One teacher mentioned giving students two or three different concepts and letting them link these together in a certain way: “I give them two or three concepts that they have to link together and I see what connections they come up with.” Another teacher mentioned how having students make relations between variables themselves helps them see how a system works together: “I reference to it beforehand and I have students make relations between variables themselves, have them define and work out concepts to see how a system works together. You can use it that way to give the students insight. When the student build something, you can evaluate what they do and if they perform enough steps. Where are their blind spots? How can I help with that? Then it is really an instrument for me as a teacher."

Computational modelling: Several teachers mentioned computational modelling. Two teachers mentioned their tendency to use computational models because it gives their students the ability to make predictions. Based on these predictions, the students can then perform experiments to gain real-life data to compare with the model. Another teacher mentioned a browser program in which students could easily build their own model with blocks. They liked this program because it was easy to make and change connections between variables. Computational modelling was the only form of teacher experience mentioned by other stakeholders. There was some examples made in which they used computer models in their classrooms when teaching. One participant mentions: "There are many apps to simulate phenomena. In Chemistry for sure, they are usually in a foreign language, but that is okay."

Qualitative/quantitative modelling: One teacher mentioned the difference between qualitative and quantitative MbL and explained how they apply both in class. Quantitative MbL meant to them that they were going to investigate a relationship between variables by measuring one while controlling the other. This could then become a formula and a graph, which they saw as models. These could then be used to make predictions. For qualitative modelling, the teacher used analogies. They mentioned how they give students an analogy which they have to use to explain a certain phenomenon.

Didactical models: Some teachers mentioned the use of models in their classrooms to visualize certain systems. These models were not built or used by the students and the students were not modelling during the class, but the models were used by the teacher to aid students' understanding of a phenomenon. One teacher mentioned having a set of tennis balls in their classroom to use when visualizing a double star system or the moon. Another teacher said: "We deal with modelling a lot when we are talking about cell biology and organs, then it becomes very abstract for the students. Same for DNA and that kind of stuff. So, I let them physically replicate it with candy wrappers and paper and those kinds of things. We do that a lot in Biology. I think we use it to make it more concrete and visible what those non-visible parts of cells and structures look like."

Discipline-specific general Models: One Physics teacher mentioned how they use one general model that is prominent in their subject, in this case the particle model, to explain a range of different phenomena to their students. They first teach the students about this model and then let it come back into different lessons and different phenomena.

## 4.3 Curriculum integration and challenges

General curriculum integration: Stakeholders gave their opinions on how well modelling is currently integrated in the curriculum. Some mentioned that it is embedded in some ways. One participant said: “I think at the VMBO level [pre-vocational secondary education], the use of a model is good enough. At the national exams, we try to minimize the amount of text, so it just would not fit in. I think at this level, students do not need to be aware of simplifying reality.” Another stakeholder agreed, stating that in higher levels like HAVO and VWO [pre-university secondary education], models and modelling play a bigger role in the curriculum. Two stakeholders mentioned the core objectives: “In the national learning outcomes, it says for both HAVO and VWO that students now have to be able to alter mathematical and qualitative models.” Some stakeholders mentioned that they think modelling should be included more: “Modelling, I think, in Chemistry education, especially lower secondary, I think it should be added way more.” Another participants said the same for higher secondary Biology education.

Time constraints: Teachers and stakeholders widely note the challenge of integrating MbL into the curriculum due to time limitations. Many teachers note that the curriculum is already quite packed, and they do not see how there is space for MbL. They mentioned how MbL can be very time intensive. Students must learn how to use the software or other tools, which takes a lot of time. One teacher mentioned how “You have to invest a lot until it actually yields something.” However, another teacher mentioned that MbL can actually reduce workload and time constraints on the curriculum. By teaching through one overarching model, time spent on instructing becomes less, and the teacher also has to only understand and teach this one model: “They always think it is way too packed and I agree. I am a Biology teacher myself and I think it is overloaded, but I think that when you can stimulate the students' systems thinking and help them work think in a model type way. If they understand everything through one model, like ... said, you only have to understand and teach this one model.”

Differentiation: Some participants mentioned how the amount of students in the classroom makes it difficult to practice MbL, as this style of teaching requires a lot of differentiation: “Differentiation in the classroom also plays a big role. I don't think I should let all students do the same thing, some students are further along than others. That also takes time in the organisation of the teacher, but it is really good to have multiple options for students so that one can dive a little deeper into the material while the other is still working on the descriptive facts and calculations.”

Urgency: Several teachers mentioned that a sense of urgency can influence the integration of MbL into the curriculum. One teacher clarifies how with the current curriculum, teacher do not feel the need to implement modelling assignments: “At different schools where I worked, it was like, why is a model important? Most of my colleagues would rather skip the modelling assignments, because it never really appears that way on the exam anyway.” If there is a sense of urgency, many teachers are willing to put more effort into finding software and teaching methods that align with MbL. This sentiment is echoed by some stakeholders that strongly suggest incorporating modelling more into the national learning outcomes and final exam requirements. One participant mentioned: “If it is not in the national final exams, it gets less attention.” Another mentioned the power of the syllabus: “So if CITO [Dutch national educational assessment organization] gives it more attention in the exam, it finds it way into the curriculum.” One teacher mentioned that some teachers are quite stubborn, so the only way to get them to feel this sense of urgency or change is to first integrate MbL into the national learning outcomes.

<u>School/teacher culture:</u> One teacher mentioned how school culture plays a role. If the school in which the teacher works at is more traditional, MbL will be accepted less, which can make it harder for teachers to implement it into their curriculum. This sentiment is supported by another teacher, who further suggests that some teachers are too stubborn to implement other forms of teaching than their own. One stakeholder mentioned teacher resources as a contributing factor: “There are many teachers in the Netherlands that are doing amazing things, but at the same time, there are a lot of teachers that do not have a pracitical lab or technical education assistant or anything due to budget cuts.”

## 4.4 Teacher support and needs

<u>Teaching and evaluation materials:</u> Teachers mentioned the need for different teaching tools and methods. Some teachers expressed the need for knowing what tools exist to use, others wanted to know how to teach or assess MbL. A common point is made on the need for solid and available tools. One participant mentioned the need for exemplar exam questions as they “were really struggling coming up with exam questions on modelling,” which made it so it was not explicitly incorporated into the exam. Several teachers also mentioned how it would be nice to incorporate MbL more into textbooks and assignments in teaching materials offered by publishers. However, other stakeholders, under which authors or publishers, mention how they “don’t really know how to incorporate it.” One author says: We do not have a textbook in subject didactics in Biology. We are struggling with that for a while now and some old colleagues wanted to write one, but we do not have the time. So it is just not there.”

<u>Learning community:</u> Several teachers expressed gratitude for the network they have with other teachers and researchers to discuss MbL. One teacher mentioned this by saying “I agree that it is very important to talk to other people who are also doing this so that you can brainstorm together.” They further suggest that more research on the best teaching practices for MbL, specifically in the context of the Dutch educational system, is necessary.

<u>Continuous learning progression:</u> Two teachers expressed their need for clear continuous learning progression throughout the secondary education system. One teacher mentioned

how nice it would be to have a guideline through the entire curriculum. They mention their experience with other teachers: “Something I hear when talking to Physics colleagues, when we talk about computational modelling, one says they do that in their fourth year, another in the fifth year, but I think it should come back every year, when talking about final exam subjects.”

Teacher training: One teacher mentioned that teachers would be more likely to incorporate MbL if they had more affinity with the technical aspects of modelling, specifically for computational modelling. Some stakeholders agree with this, suggesting that teacher training is widely needed. They think teacher training is necessary to develop teachers’ scientific literacy and their own understanding of models, and teachers need to know how to properly assess exams about modelling. Furthermore, teacher training is necessary to create awareness, especially among teachers, but also students: “if we want modelling to become more recognized in high schools, we need to start by raising awareness among teachers and equip them with proper tools and knowledge, so that they are capable of teaching this.”

# 5 Conclusions

In this report, we present findings from four focus group interviews with Dutch teachers and stakeholders concerning their experiences and views on Modelling-based Learning (MbL) in the Dutch educational context. Most teachers and stakeholders viewed the learning goals of science education as supporting students in becoming good critical thinkers, promoting social responsibility and awareness, developing meta-cognitive awareness of scientific thinking, and advancing practical scientific skills. In the following sections, we report the results based on the four aspects that guided the focus group interviews: knowledge about MbL, teaching experience, curriculum integration, and teacher support and needs.

Knowledge about MbL

Most interviewed teachers and stakeholders view models as representations of reality, with some debate among stakeholders regarding the question of whether formulas and scientific laws can be considered as models. They state that models should have a purpose, mostly related to understanding the investigated phenomena and making predictions. Some also mentioned that it is important for students to understand that there could be multiple models representing the same phenomenon.

Modelling was perceived by most participants as a dynamic process that includes constructing, testing, revising, and using models to understand, predict, and explain. Some teachers stressed the social aspects of modelling as a collaborative product of the science community. Some debate among teachers concerned the boundaries of the modelling process, mostly whether only using models can also constitute as modelling. Teachers also mentioned the mathematical aspects of the modelling process. Most participants viewed

Modelling-based Learning (MbL) as the active process of engaging with models, mostly stressing using models as epistemic tools to construct their own meaning and knowledge of phenomena. Both teachers and stakeholders also mentioned the interdisciplinary aspects of MbL, aiming at connecting perspectives from different fields when developing and using models.

Concerning teachers' knowledge about MbL, most teachers mentioned their personal interest in the topic as key motivation, together with their goal of shifting towards active student-centered pedagogy. Some teachers mentioned that they gained experience with models and modelling by performing research. Interestingly, several teachers mentioned they did not learn about models and modelling during their teacher training.

Teaching experience

As for teachers' experience with MbL, several mentioned using concept maps as the main modelling approach. Several teachers also mentioned using computational modelling tools where students can construct their own models, test them with real data, and make predictions. Stakeholders mostly mentioned computational modelling tools. Teachers also mentioned the difference between qualitative and quantitative models, some discussed how they use models as didactical tools to visualize the investigated systems, and one teacher discussed a discipline-specific general model that they use in different lessons.

Curriculum integration

Stakeholders had different views regarding the extent to which modelling is integrated into the curriculum at the higher and lower educational levels (VMBO, HAVO, and VWO), with some suggesting it should be better integrated. Both teachers and stakeholders mentioned that time restrictions is the main limitation for fully integrating MbL into the curriculum, since it is a heavily time-consuming activity and the curriculum is already very full. Some participants also discussed issues related to differentiation between students in the classroom, mentioning that the curriculum should address students' different cognitive abilities and pace of learning. Another factor limiting the integration of MbL into the school curriculum that was mentioned was the school culture and teachers' dispositions towards MbL.

In general, both teachers and stakeholders agreed that the integration of MbL into the curriculum depends on the urgency, meaning that if students will be tested on this in their final exams, the integration will be fast and efficient. Participants discussed that modelling does appear in the final examination, but the curriculum emphasises using models rather than modelling as a process. Teachers reported that exam expectations reinforce the application of established models rather than iterative model development.

Teacher support and needs

Teachers mostly mentioned their need to learn about different modelling tools, have more tools available for classroom use, and experience more MbL teaching methods. They also mentioned that they need more MbL teaching and learning materials, such as textbooks and classroom assignments, and exemplar exam questions. Some stakeholders, on the other hand, mentioned that they don't know how to incorporate MbL into their textbooks. Several teachers also discussed the need for a network and learning communities of teachers that are interested in MbL so they can share their experiences and learn from each other. Several teachers mentioned that they want to have a clear learning progression of MbL for secondary education provided to them. Some participants also mentioned there is a need for more technical support and professional development for teachers in using computational modelling tools in the classrooms, and to develop teachers' and students' awareness towards models and their purpose in science.

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