Master thesis

Defining learning objectives for using and designing models in science, mathematics, and technology subjects in lower secondary education

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Abstract: This study focuses on defining learning objectives for using and designing models in science, mathematics, and technology subjects in lower secondary education. In our current science education, we put emphasises on a more coherent science education that incorporates the 21st century skills. Nowadays, the implementation of these skills is still insufficient. A better implementation of the 21st century skills and a more coherent science education can be achieved by putting more emphasis on models in education. However, grounded learning objectives for using and designing models in lower secondary education are still missing and consequently we cannot propose suitable learning and teaching strategies. Therefore, the aim of this research is to get a better view on what we want to teach students in lower secondary education about models. As part of this, the meaning of the term model and related concepts need to be clarified. To do this, eight semi-structured interviews are conducted with experts with a background in one of the science, mathematics, or technology subjects and a background in educational research. The analysis of these interviews shows that the term representation is closely related to the term model and that models are by the experts seen as a representation of something. Furthermore, a selection of most desirable learning objectives for using and designing models is identified. The achievability of the learning objectives depends on how complex the model is and how complex the object is that is (going to be) modelled.

Keywords: Scientific and Engineering Practices, Kennisbasis, models, modelling, science education, learning objectives

Contents

Introduction

In our ever changing society, we try to improve education year after year. To be able to do this, it is important to decide what knowledge and skills the students need in order to be prepared to function in our society. Many of the skills that are emphasized nowadays are the so-called '21st century skills' (Thijs, Fisser, & Hoeven, 2014). Thijs et al. (2014) identified eight of these 21st century skills: creativity, critical thinking, problem-solving, communication, collaboration, digital literacy, social and cultural skills and self-regulation. The implementation of these 21st century skills in the Dutch curricula is still insufficient (Bureau Platform Onderwijs2032, 2016; Thijs et al., 2014). Even though the curricula give teachers some space to teach 21st century skills, the lack of explicit attention to these skills in both the curricula and the methods make it hard for teachers to know what to teach and how to teach it (Thijs et al., 2014).

In working with models, students use and develop many 21st century skills. Models can be used in solving problems and in communication. Students can use either existing models or create models themselves. Using existing models, for example to base their argumentation on, requires critical thinking: students can learn to reason why one model is trustworthy and another is not and can argument why they use specific models. Creating models, on the other side, requires creativity and analysing skills.

Furthermore, working with models gives students more insight in the nature of science (NOS). Models have always been of huge importance in scientific research. Models are essential in studying complex phenomena. They play a significant role in both the formulation of hypotheses that need to be tested and in describing scientific phenomena (Gobert & Buckley, 2000; Gilbert, 1995).

Models are crucial in science education as well (Gobert et al., 2011). They are widely used in science textbooks (Gilbert & Boulter, 2000; Vos & Valk, 2000) and teachers use models as teaching aids to describe structures and processes (Harrison, 1996). The usage of models makes it possible to show students scientific phenomena that cannot be reproduced in the classroom because of time and safety constraints (Harrison & Treagust, 2000), because it is too small or too big, or because it is too fast or too slow for direct perception (Gilbert & Boulter, 2000, H6, p. 133). Furthermore, models can help students to detect parts of a system or model (Buckley & Boulter, 2000).

The importance of models in both science and education is emphasized in the educational curricula. In the Netherlands, the curricula for science subjects are described in the Kennisbasis natuurwetenschappen en technologie voor de onderbouw vo *('knowledge base* science and technology for lower secondary education'; from now on referred to as *Kennisbasis*) (Ottevanger et al., 2014) and the examination programs (College voor Toetsen en Examens, 2012a, 2012b). In the *Kennisbasis*, 'developing and using models' is one of the 'karakteristieke werkwijzen' ('*Scientific and Engineering Practices'* in K-12, from now on referred to as *practices*). To make these *practices* usable for teachers, teaching and learning strategies are needed. However, so far few explicit teaching and learning strategies about models have been described.

One of the main reasons for this lack of learning strategies is that it is unclear what we want to teach the students. Without clear learning objectives, we cannot propose suitable learning strategies. This has partly to do with the fact that the terminology concerning models is unclear (Justi & Gilbert, 2003). The term *model* has many different meanings in everyday language use, and in science it has multiple closely related terms that are sometimes used interchangeably (Bertels & Nauta, 1969, p. 33). Furthermore, the distinction between models in science and in education is seldom made in literature.

Therefore, the aim of this research is to get a better view on what we want to teach students in lower secondary education about models. To do this, the terminology around models needs to be unravelled, the current views on models need to be explored and it has to be studied what learning objectives concerning models can be found in literature and what arguments can be used to choose between them.

Theoretical Background

In the introduction it was already mentioned that models are essential in scientific research and in science and technology education. Without models it is hard, if not impossible, to learn and educate about the world. The more people learn about natural phenomena and social processes, the more they feel the need to simplify the increasing information flow – preferably without removing the important aspects of the object of study (Bertels and Nauta, 1969, p. 28-30). By using models, the big mass of information can be decreased and therefore the phenomenon observed can become less complex to comprehend and more insightful (Bertels and Nauta, 1969, p. 28-30).

Phenomenon, expressed model and mental models

From abovementioned, it can be deduced that models can be placed in a bigger picture, also including phenomena and people's ideas about phenomena. Buckley and Boulter (2000, pp. 120-123) describe this connection in a model similar to the model expressed in Figure 1.

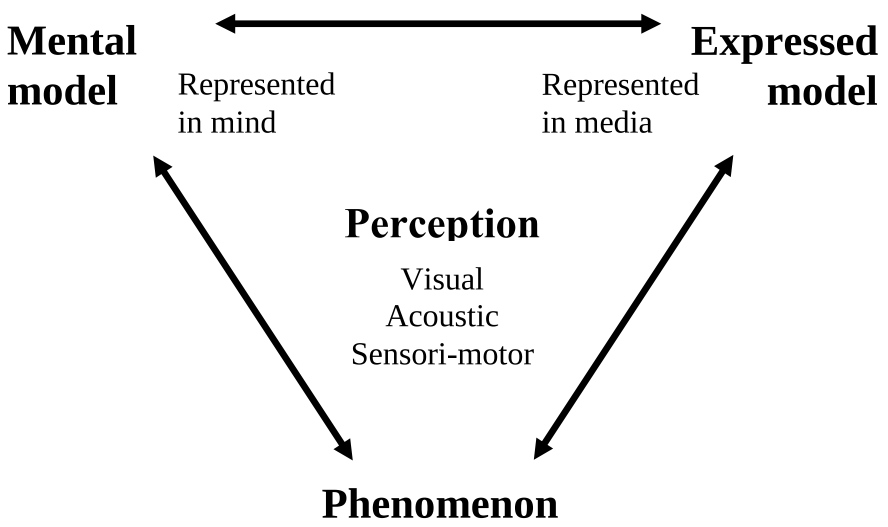

Figure 1. The relationship between phenomena, mental models and expressed models; based on Buckley & Boulter (2000, p. 121).

In this model, it is assumed that when people solve problems or try to explain or clarify phenomena, they use both internal and external representations (Larkin & Simon, 1987). About the meaning of the double-headed arrows, Buckley and Boulter (2000, p. 120) say the following:

> *Mental models are used both to understand and to create expressed models. They influence our perceptions of phenomena, which in turn influence our mental models. Expressed models represent selected aspects of phenomena and of mental models.*

Mental models

Buckley and Boulter (2000) describe mental models as 'internal, cognitive representations used to reason about phenomena, and to describe, explain, predict, and, sometimes, control them'. Vosniadou (1994) gives a definition that emphasizes the private nature of mental models (Corpuz & Rebello, 2005) and how mental models are used as well, but also describes

the dynamic nature of models and how mental models are generated: ‘Mental models are dynamic and generative representations which can be manipulated mentally to provide causal explanations of physical phenomena and make predictions about the state of affairs in the physical world’.
Because of their private nature, mental models are inaccessible and ‘intrinsically difficult to investigate’ (Coll, 2006; Corpuz and Rebello, 2005). To be able to say something about mental models, we therefore rely on the expressed version of these mental models: often referred to as an expressed model (Coll & Treagust, 2003; Corpuz & Rebello, 2005).

Expressed models
Expressed models are mental models represented in the public domain (Coll & Treagust, 2005). This means that, in contrast to mental models, these are external models. By creating models, people can express their mental models and, by doing so, express their personal understanding of phenomena by externalising their ideas (Chiu & Chung, 2013). This makes expressed models suited for public use and interaction (Coll & Treagust, 2003); for sharing ideas, learning and teaching.
According to Coll and Treagust (2003), expressed models can be characterised by the nature of these interactions:

> *When this interaction concludes that the expressed model is of value, it is described as a consensus model (Norman, 1983). Consensus science models that are subject to and survive rigorous experimental testing, published in scientific literature, and widely accepted by the scientific community, are called scientific models.*

Besides identifying consensus models and scientific models, Coll and Treagust (2003) describe a third category: teaching models. These are ‘mental models as presented by teachers’ (Coll & Treagust, 2003). However, these teaching models are also publicly interacted with and this is why they add another category of models: the consensus teaching models.
However, the interaction between expressed models and mental models goes the other way around as well, as can be seen in Figure 1. Expressed models can contribute to the formation and elaboration of mental models of phenomena (Buckley & Boulter, 2000; Chiu & Chung, 2013).
It has to be noted that different expressed models show only part of a phenomenon, and therefore expressed models facilitate access to only selected parts of a phenomenon (Buckley & Boulter, 2000). In education, the forming of correct mental models about phenomena can therefore be supported by teachers providing different expressed models and supporting different ways of working with models, like talking, writing, drawing and interacting with expressed models (Buckley & Boulter, 2000).

A definition of models
In research, different definitions and synonyms are used for the term *model*. A general definition that will be used to describe models in this paper is the definition by Ingham and Gilbert (1991) and Gilbert (1995) as it was combined by Gobert and Buckley (2000):

> *A model is a simplified representation of a system, which concentrates attention on specific aspects of the system. Moreover, models enable aspects of the system, i.e., objects, events, or ideas which are either complex, or on a different scale to that which is normally perceived, or abstract to be rendered either visible or more readily visible’.*

This definition will from now on be referred to as 'Gilbert's definition'.
Even though this definition is frequently used in recent educational literature (Al-Balushi, 2013; Gobert & Buckley, 2000; Gogus, 2012; Maj, Ohtsuki, Akamatsu, & Mackay, 2016; Stoltenkamp, 2012), there is still not one definition that is widely accepted.
There are some terminological problems considering the confusing terminology around the term *model* (Justi & Gilbert, 2003). First of all, the term *model* has multiple different meanings in everyday language use (Bertels & Nauta, 1969, p. 19-22; Chamizo, 2013). Second, in science, many different terms are used to talk about models in science. For example, Duit (1991; Sibley, 2009) state that 'model and analogy are frequently used interchangeable'. Another term that is often used in educational literature about models is the term *representation*. (e.g. Clement, 2000; Schilhab, 2007). Bertels and Nauta (1969, p. 33) name fourteen other closely related terms. Translated from Dutch, these are: *image, icon, reflection, exemplum, metaphor, scheme, paradigm, mold, mould, pattern, facsimile, isomorphism, homomorphism* and *homology*[1]. Gilbert, Boulter and Elmer (2000, p. 15) furthermore name three terms that specifically in design and technology education are sometimes used instead of the use model: *mock-up, lash-up* and *prototype*.
To get more knowledge about the meaning of the term *model* in both everyday language and scientific language, more information is needed on the semantic background of the term *model*. Furthermore, it is important to find out what different beliefs of the meaning of the term *model* are held in different groups of people.

Models from a semantic point of view
The term *model* comes from the Latin word *modulus*, which means something like 'small size'. The Latin *modulus* was named first in a book by Vitruvius, an architect from the first century before Christ. It was not until about the 16th century that the term *model* came closer to the meaning it has now. According to Bertels and Nauta (1969), the term *model* around this time means something like: *miniature in clay or plaster, copy,* and *example, pattern, ideal*. Shortly after this, the term *model* also gained meaning in science. (Bertels & Nauta, 1969, p. 19-22)
Nowadays, *model* is an ambiguous term that is used with several meanings in both science and everyday language (Bertels & Nauta, 1969, p. 19-22; Chamizo, 2013). Since the term *model* was taken up in the modern languages, almost none of the meanings have disappeared. In science and in the classroom, the term *model* has double meanings as well. According to Chamizo (2013), this is one of the problems when using the term in teaching.

Models in science
As already is pointed out, models are important in scientific research. They come in all forms and shapes (Coll, 2006) and have different usages. However, to be able to use the scientific way of working with models to gain more coherency in the science subjects, looking at the general features of scientific models is more interesting than looking at all the differences (Vos & Valk, 2000). Such features make it not only possible to look at separate models used in education, but also to put more emphasis on working with models as a skill. Vos and Valk (2000) underline that by doing this, it is possible to offer students a coherent treatment of models in science subjects.

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[1] Beeld, icon, afspiegeling, metafoor, exempel, schema, paradigma, matrijs, mal, pattern, fascimile, isomorfie, homomorfie, homologie

Driel and Verloop (1999; Driel, 1999) posed seven general features of scientific models, based on an analysis of scientific literature consisting publications from mainly the history and philosophy of science (Valk, Driel, & Vos, 2007). These seven characteristics have been evaluated in different studies (Vos & Valk, 2000; Valk, Driel, & Vos, 2007), resulting in revision of the seven features, describing the nature and functions of a model. The resulting eight features are shown in Figure 2. The first two features describe the nature and functions of a model, the features 3 and 4 refer to the criteria a model must fulfil in science and the last four features describe the selection and development of a model (Valk, Driel, & Vos, 2007).

Feature 1:	There is a strict distinction between model and target
Feature 2:	A model serves as: a. A research tool that is used to obtain information about the target which itself cannot be easily observed or measured directly; b. A representation of scientific knowledge about the target, to be used to facilitate making decisions about issues (in technology, medicine, society, ...)
Feature 3:	a. Within the realm of its valid use, a model bears some analogies to the target b. These analogies enable the researcher to reach the purpose of the model; in particular to derive hypotheses from the model or to make predictions, which may be tested while studying the target
Feature 4:	A model differs in certain respects from the target. The differences make the model more attractive for research than the target
Feature 5:	Since having analogies (3.a) and being different (4.) lead to contradictory demands on the model, a model will always be the result of a compromise between these demands
Feature 6:	The construction of a model requires creativity, among others in finding a compromise between 'having analogies with' and 'being different from' the target, so as to optimally serve its purpose
Feature 7:	Several consensus models may co-exist with respect to the same target. However, depending on the precision requested (e.g., the precision of the predictions based on the model; the design specifications), one model can be the best, at least for the time being
Feature 8:	As part of the research activities, a model can evolve through an iterative process.

Figure 2. General features of scientific models as described by Valk, Driel and Vos (2007).

According to Valk, Driel and Vos (2007), a good start in improving student understanding of the nature and functions of models in present-day scientific research, would be to pay more attention to these modern uses of models and the nature of models in science curricula and science text books.

Models in technology

Nauta and Bertels (1969, p. 44) categorize the different school subjects relevant for this study as follows: mathematics is part of the formal sciences (together with all sciences, for as far as they are formalised); physics, chemistry, biology, and physical geography are part of the natural sciences; and technology belongs to the applied sciences, together with medicines. However, they note that 'all applications of other sciences' belong to the applied sciences as well. This means an overlap between all the fields.

Nauta and Bertels emphasize that there are similarities between the nature of science and technology in respect to models and modelling, but state that they are not the same. Gilbert et al. (2000, pp. 14-16) agree with this, and emphasize that – contrary to science education – in technology and design education the emphasis lies on designing: the student acts as a 'designer'.
Gilbert et al. (2000) describe this design process, which starts with a translation of a mental design (mental model) to an expressed model, as follows:

> *This is then subjected to a cycle of development testing, further development, and so on, until the designer is convinced that the outcome can be presented to the client (or, in an educational context, the teacher-as-surrogate client) in the form of a* prototype. *This prototype willl be subsequently altered in response to the client's reaction and, perhaps more significantly, in the light of the material sused in fabrication when the product is manufactured.*

This means that models produced in technology are created to find the solution on a problem and used to evaluate this solution before a final product is produced. This is different from the functions of models in scientific research. However, as Gilbert et al. (2000) point out: 'the purpose of modelling in both fields is to facilitate communication through a visualisation of the relation between the intention and the outcome of the activity'. Furthermore, in both creating a scientific model and a design model, different expressed models are made 'towards a version which is socially accepted' (Gilbert et al., 2000).
Because of this, models and modelling have potential of connecting technology education with science education.

Models in science education
Models are widely abundant in science education. They can give students more insight into complex situations (Ottevanger et al, 2014) and can be an aid in predicting and analysing problems. To be able to use models properly, it is important that students have knowledge about the nature of models. Students need to understand that in models, assumptions are made and that you work with approximations.
In the classroom, there are several conditions that play an important role in how students learn with and about models. Probably the most obvious two are textbook content and teacher knowledge. Both of these conditions will be discussed for the present-day educational practice.

Textbook content
The textbooks used in science education are a vital source of models in science education. According to Erduran (2001), models in those textbooks (or at least in the chemistry textbooks she studied) are not explained in terms of why they are used and how they differ from other models. Valk, Driel and Vos (2007) describe this as models often being presented as facts. They stress that 'features such as the relation between model and target (Feature 1), possible limitations of a model (Feature 5), or the way in which models are developed (Feature 8), are seldom addressed'. According to Abd-El-Khalick, Waters, and Le (2008), who investigated the occurrence of aspects of the nature of science in different chemistry books, the analysed textbooks show very little attention to the aspects of the nature of science overall. They furthermore stated that if the nature of science is discussed, this is done in statements rather than in models.

Valk, Driel, & Vos (2007) also note that there is a lack of assignments that stimulate students to create or test models. This is confirmed by Abd-El-Khalick, Waters, and Le (2008), who state that ‘nearly no activities, questions, or reflective prompts focused on NOS’.

Teacher knowledge
Different studies investigated teacher knowledge about modelling and the nature of models. Justi and Gilbert (2003) tried to identify different levels of understanding, but could not find such levels. They concluded that this probably means that teachers ‘do not hold coherent ontological and epistemological views’. This means that teachers probably have scientific accepted views on several aspects of the nature of models, but not on all those aspects. It is important that teachers improve scientific views on all aspects of the nature of models, and that they get more knowledge about the other aspects too. This, in order for them to understand students’ displays of ‘scientifically unacceptable’ views (Justi & Gilbert, 2003). Driel and Verloop (1999) also studied teachers’ knowledge of models, with their focus on experienced science teachers. They also found that there is a great variation in beliefs that teachers have and their research showed that teachers emphasize different functions and characteristics of models. Furthermore, Driel and Verloop (1999) state that the knowledge of models and modelling in science of the teachers is often limited. According to Valk, Driel, & Vos (2007) this might be one of the causes for the low understanding that students have about modelling and the nature of models.

Student knowledge
In the light of the 21st century skills and students’ knowledge about the nature of science, much research is performed on the understanding of the role of models in science. This research shows that students have little knowledge about the nature of models and the application of models in science (Gobert et al., 2011; Carey & Smith, 1993; Driel & Verloop, 1999).
Several studies have been produced to identify different levels of thinking about models (Carey & Smith, 1993; Grosslight, Unger, Jay, and Smith, 1991; Justi & Gilbert, 2003; Krell, Upmeier zu Belzen, & Krüger, 2014).
Justi and Gilbert (2003) looked at teachers’ understanding of models and did not find such levels (Justi & Gilbert, 2002). However, Grosslight et al. (1991) were able to identify three levels in their study on student’s thinking about models. Level 1 describes the lowest level of understanding, in which the student sees models as either toys or as simple copies of reality (Carey & Smith, 1993). Level 2 understanding includes that the model is seen as constructed with some kind of purpose. Nevertheless, Carey and Smith (1993) emphasize that the focus is still on the model and the reality it models, and not on the ideas it presents. Level 3 describes the understanding that models are tools used in the construction and testing of scientific theories. This is the level of understanding that is seen in expert scientists (Carey & Smith, 1993).
Grosslight et al. (1991) identified those three levels after interviewing seventh and eleventh graders and scoring their responses on six separate dimensions: the role of ideas, the use of symbols, the role of model makers, communication, testing and multiplicity of models (Carey & Smith, 1993; Chittleborough & Treagust, 2007). They found that 67% of the seventh graders were at Level 1, 12% at Level 2 and 18% Level 1/2 (Carey & Smith, 1993). Of the eleventh graders, only 23% were at Level 1, 36% were at Level 2 and 36% had a score between Level 1 and Level 2 (Level 1/2) (Carey & Smith, 1993; Chittleborough & Treagust, 2007). Only a few students demonstrated an understanding of models as described by Level 3 (Erduran & Duschl, 2004).

This is a concerning outcome, because several studies have shown that the understanding of models is related to the science learning of students (Gobert et al., 2011; Gobert & Pallant, 2004; Schwartz & White, 2005). In designing learning objectives it is therefore important to describe learning objectives that are explicitly aimed on the nature of models.
It can be concluded that both textbook content and teacher knowledge concerning models seem to be insufficient. Valk, Driel and Vos (2007) suggest that improvement can be achieved by increasing textbook authors' and science teachers' awareness of the nature of models. However, 'awareness' might not be enough to improve students' knowledge about models: a clear description of objectives is needed as well. As long as no clear goals and descriptions are provided in science curricula to describe what student's need to learn about models, it is difficult for textbook authors and science teachers to know how meet the expectations.

About models in the Dutch curricula
In the Netherlands, the blossomed attention to models and modelling experienced in secondary education is reflected in the *Kennisbasis* science and technology for lower secondary education (Ottevanger et al., 2014) and in the Dutch examination programs (Subdomein A7 Modelvorming; College voor Toetsen en Examens, 2012a, 2012b). Models are also named as an important part of the nature and technology subjects in the final advice by Ons Onderwijs2032: an advisory report for a new curriculum for primary and secondary education in the Netherlands (Bureau Platform Onderwijs2032, 2016). However, because the focus of this study is on lower secondary education, only the *Kennisbasis* will be discussed in more depth.

The Kennisbasis
The purpose of the *Kennisbasis* is to provide clarity on relevant learning objectives and learning content for mathematics, physics, chemistry, biology, physical geography (as part of the subject geography) and technology for lower secondary education (Ottevanger et al., 2014). It was decided to use an interpretation in which all the fields mentioned are described in three closely interrelated dimensions: *Disciplinary Core Ideas* (vakinhouden), *Scientific and Engineering Practices* (karakteristieke werkwijzen) and *Crosscutting Concepts* (karakteristieke denkwijzen) (Ottevanger et al., 2014). This classification is closely based on the three dimensions of the framework for K-12 Science and describes what it means to be skilful in science (National Research Council, 2012).
The three dimensional learning approach is aimed to promote coherence in science education (Legierse, Heijnen, & Thurlings, 2006; National Research Council, 2012). This emphasis on coherent science education fits the Dutch *doorlopende leerlijn* (learning progression that is described for Dutch upper secondary education): in upper secondary education there is a strive for more coherence between the different disciplines as well (Boersma, Bulte, Krüger, Pieters & Seller, 2011; Ottevanger et al, 2014).
Within the *Kennisbasis*, seven *Scientific and Engineering Practices* are described. The *practice* specifically about models and modelling, is called 'modelontwikkeling en -gebruik' (Ottevanger et al., 2014), which is similar to the *practice* 'Developing and using models' from the K-12 Science (National Research Council, 2012).

Learning objectives about models in Dutch curricula
In a supplementary document published by the SLO, Spek and Rodenboog-Hamelink (2011) describe several learning objectives in a learning progression for the practice 'developing and using models' as part of the 'natuurwetenschappelijke vaardigheden onderbouw havo-vwo' (scientific practices lower secondary school).

They discuss four different phases: 1) characteristics, 2) function, 3) usage, and 4) evaluation and reflection. For each phase, Spek and Rodenboog-Hamelink (2011) describe four levels: a starting level, an undefined level that describes a slightly more advanced knowledge about models, and two entry levels for the first grade of upper secondary education (tenth grade): one for regular students and one for the so-called 'plus'-students.
The learning objectives defined by Spek and Rodenboog-Hamelink (2011) and the statements they make about models seem to be – based on their reference list – grounded on one source; the book 'Inleiding tot het modelbegrip' by Bertels and Nauta (1969). Although this book gives an insightful view on models in science, it does not say much about models in education or about how students learn about models and modelling. Plus, since the release of this book, new insights have been shown in literature. However, these learning objectives can still give us an idea of how learning objections can be defined in a learning progression. Plus, it gives us some suggestions of meaningful learning objectives in relation to model learning in lower secondary education.

Learning objectives about models in K-12
The National Research Council (2012) described learning objectives in the framework for K-12 Science, as part of the section about practice 2: Developing and using models. They emphasize the importance of models in both science and engineering and describe five learning objectives that students should be able to reach by grade 12, covering the following activities:

- Constructing models as representation of events or systems
- Representing and explaining phenomena with multiple types of models
- Discussing the limitations and precision of a model
- Using simulations as tool for understanding and investigating
- Making and using a model to test a design

They also say something about the progression: starting 'from concrete "pictures" and/or physical scale models' to 'more abstract representations of relevant relationships in later grades'. 'Students should be asked to use […] models as tools that enable them to elaborate on their own ideas or finding and present them to others' and 'young students should be encouraged to devise pictorial and simple graphical representations of the findings of their investigations and to use these models in developing their explanations of what occurred'.

About learning objectives in educational research literature
In educational research, several authors describe learning objectives for using models and modelling (Gilbert, 2004; Schwarz, Reiser, Acher, Kenyon, & Fortus, 2012; Vos & Valk, 2000).
Schwarz et al. (2012) wrote an article about 'defining a learning progression for scientific modeling' in 'upper elementary and middle school classrooms'. They emphasize the importance of engaging learners: 1) 'in modeling components, processes, and mechanisms that can explain and predict phenomena'; 2) 'in reflective practice in which scientific activity is meaningful to them', 3) 'in the modeling practice itself'. They emphasize the scientific practice of modelling in their learning progression, including four elements:

- *Constructing models consistent with prior evidence and theories to illustrate, explain, and predict phenomena;*
- *Using models to illustrate, explain, and predict phenomena;*
- *Comparing and evaluating the ability of different models to accurately represent*

and account for patterns in phenomena and to predict new phenomena; and
- *Revising models to increase their explanatory and predictive power, taking into account additional evidence or aspects of phenomena.*

Furthermore, they emphasize the importance of 'Conceptualizing modeling as a general scientific practice'.
Vos & Valk (2000) interviewed 26 scientific researchers with a background in natural sciences about the use of models. Based on the opinions of the researchers they interviewed, they made a list of what activities should be playing a role in case of meaningful learning:

- *assessing whether a model is desirable or necessary in a particular situation*
- *if yes, then: choosing or designing one or more suitable models*
- *deriving relevant hypotheses and/or predictions from a model*
- *and then, improving the model and using it again*

Vos and Valk (2000) add that this should be accompanied 'by a research context in which working with models is meaningful and can be sensed as meaningful'.
Gilbert (2004) investigated the possibility towards a more authentic science curriculum on the basis of models and modelling. He states that 'any science curriculum based on models and modelling must provide the opportunity for pupils to develop the capability to produce and test their own models'. Gilbert (2004) describes via which steps this takes place:

1) *Learning to use models*
2) *Learning to revise models*
3) *Learning the reconstruction of a model*
4) *Learning to construct models de novo*

Gilbert (2004) furthermore gives three goals to describe 'successful learning' in 'the model-based curriculum', namely: 'having an acceptable understanding of what a model is,' 'having a developed capacity to mentally visualise models', and 'having an acceptable understanding of the natures of metaphor and analogy'.

Search for scientific based learning objectives
Even though learning objectives are described, there seems to be a lack of learning objectives that are based on the current scientific knowledge on this subject. On the way to grounded learning objectives for model learning in lower secondary education, there are several questions that need to be answered. To begin with, it needs to be clear what the term *model* means. What are the different meanings assigned to the term *model*? To what extent is the term *model* different from similar terms? Can one definition be given for models in science, mathematics, and technology education?
Furthermore, it is relevant to investigate what learning objectives should be emphasized in education, according to experts from different science fields and from different backgrounds. The purpose of this study is to get answers on these questions and to clarify these subjects. The goal is to eventually be able to formulate grounded learning objectives for model use in lower secondary education. Therefore, the research question of this study is:

What are desirable and achievable learning objectives for using and designing models in science, mathematics, and technology subjects in lower secondary education?

Method

To get an answer on the research question, eight semi-structured interviews were conducted. To be able to say more about possible common definitions, uses and characteristics for models in the different science and technology disciplines, the following sub questions will also be answered:

1. What are the different meanings ascribed to the term model?
2. To what extent can the term model be distinguished from related terms?
3. What are achievable and desirable learning objectives for designing and using models according to researchers in science education?

The Interview

To get an overview of the different meanings of the term *model* and the use of models in the different science and technology disciplines, eight semi-structured expert interviews were conducted. Researchers and educational associates from different science backgrounds were selected and interviewed. Every interview was audiotaped and afterwards transcribed and analysed.

Selection interviewees
The selection of experts took place on the basis of three criteria. The researchers had to have:

1. a background in one of the science, mathematics, or technology disciplines,
2. a background in educational research
3. knowledge about the topic models

Based on these criteria, eight experts were interviewed with the following educational background and field of expertise:

	Education	*Field of expertise*
1.	Biology	Biology education
2.	Biology	Biology education
3.	Chemistry and mathematics	Chemistry education
4.	Mathematics	Mathematics education
5.	Mathematics	Mathematics education
6.	Physics	Physics education
7.	Physics	Science and mathematics education
8.	Physics	Physics and technology education

Interview plan
The main instrument of this research is a semi-structured expert interview (Baarda, Goede & Meer-Middelburg, 1996). Pilot-interviews were undertaken on two peer master students and one researcher, in order to develop a valid and consistent topic list (see Appendix 1).
The interview consists of four sections. The first section includes an introduction in which the procedure and goal of the interview are explained. In the three sections after that, questions are asked about:

- The background of the expert (these questions function to get more knowledge about the expert and the expert's expertise. The answers on these questions will no further be discussed in this study)
- Terminology (including questions about the nature of models, Gilbert's definition of models and closely related terms)
- Learning objectives (including questions about learning objectives and features of models)

The first questions in the section terminology (Appendix 1) are based on the first two questions from the interview by Justi and Gilbert (2003) on the nature of models. They used these questions to get insight in the teachers' view and understanding of the nature of models. In this study they are used to get insight in how the experts see models and how models can be described in science education. The other questions are designed especially for this study. Besides open questions about the different subjects, the interviewees also were asked questions about four texts that were presented to them:

- Gilbert's definition of models (Ingham & Gilbert, 1991; Gilbert, 1995)
- List of closely related terms (based on a selection made out of the closely related terms proposed by Bertels & Nauta (1969), Duit (1991), and Gilbert et al. (2000))
- List of general features of scientific models (Valk, Driel and Vos, 2007)
- Scheme with learning objectives

The learning objectives in the scheme with learning objectives are derived from educational research literature (Gilbert, 2004; Schwarz, Reiser, Acher, Kenyon, & Fortus, 2012; Vos & Valk, 2000) and curricular literature (National Research Council, 2012; Spek & Rodenboog-Hamelink, 2011). The learning objectives from this literature were collected, categorized, and a selection was made and rewritten into a scheme consisting of in total 15 learning objectives concerning 1) learning with models, 2) learning about models in education, 3) learning about models in research, and 4) learning to model (see Appendix 1). Goal in making this scheme was to include a wide range of learning objectives, covering all kind of learning objectives in literature.

Data-analysis

The data-analysis took place according to the format described by Baarda, Goede and Meer-Middelburg (1996, Chapter 7). The interview material was first transcribed to protocols. Then the protocols were read and a selection was made between the relevant and irrelevant parts. Software (NVivo 11 for Windows) was used to further categorize the text that was selected as relevant for answering the research questions. NVivo was chosen, because it has a feature that puts together all text fragments with the same label. This makes it easier to compare different text fragments on the same subject.

The text fragments were categorized in three divisions: 1) Terminology, 2) Learning objectives, and 3) Features. The data selected for terminology was then further divided in a) Nature of models b) Gilbert's definition, and c) Closely related terms. The data was further divided in subgroups, in order to be able to group the answers that were given in response to each question from the topic list (Appendix 1). The answers on the questions about the background of the experts were excluded.

After categorizing all data, the different answers given on the questions were analysed, grouped, and described in text. In describing the data, it was attempted to include selected interview quotes, making it possible for the reader to get more insight in what the experts said. Since the experts were interviewed in Dutch, the quotes were translated to English.

Results

A. Nature of Models

Comments on the nature of models
Two categories of meaning are used to describe the term *model*:

1. a model is a representation of something;
2. a model is a description of something.

Most of the experts (7 out of 8) describe a model as 'a representation' of something, in which some experts described this representation as being 'a *simplified* presentation' or 'a *schematic or physical* presentation'. Additionally, some experts included in their definition that the representation 'has a certain purpose or function', 'has a role in a certain context' and 'somehow helps to better understand' what it represents.
Furthermore, there was a variety of descriptions of the "something" a model represents. Some simply called it 'reality' or 'reality that is not reality', where others were more specific: 'an object/process/idea', 'a process or phenomenon', and 'a certain structure or pattern'. From the complete interviews, four different entities could be identified: events, ideas (also: 'theories' or 'thought experiments'), objects, and processes.
One of the experts describes a model as 'a hypothetical description of reality in terms of a set of rules, which follow expectations about what could happen in reality'.

Comments on the use of models
Comments on the use concerned the contexts and the functions of models

Contexts.
Many experts indicate that models are used 'in all situations' and 'always and everywhere'. One of the experts explained this as the following:

> *'Human operating is only possible on the basis of a model of your surroundings [...] and your ideas on how people function, can – from a psychological point of view – all be considered as models. A set of rules and expectations and from the expectations can be decided on how to proceed. And you also adjust that model. This, however, happens of course implicitly. That, for me, is the base of model thinking: mental models that you have of your living environment.'*

However, inside this general context of the use of models, some more specific contexts are described: the social context, the professional context, the scientific context and the educational context.
Some experts point out that models function in the social context:

> *'I think they (models) are also very often used in social contexts. In social contexts this is more via stories and images. But also cultural-historical communicable things are models according to me. So you use models to transfer things to each other and to teach each other things. And that is in a sense about models.'*

According to some of the experts, models are used 'very often in professional contexts'. An example is given for mathematics: 'there are professional contexts in which people work with

models. […] Very actual is the financial sector, where all kind of models are used to calculate share prices'.
Other comments describe the scientific and educational contexts: 'The special thing about scientific models is that they are made very explicit. […] And that we make very explicit that the model regulations are a choice, or a hypothesis, or at least that under discussion'. 'In schools you use educational models to try to (e.g.) make mathematical principles insightful' and 'there are also certain models that students have to know.'

Uses.
Within these contexts models have different functions. The following uses of models can be abstracted from the answers the experts gave on the question 'what are models used for?':

a. Visualisation. 'Models […] make that some things are more specific visible'. 'You use the concept of representation when you really want to make something discussable or in the communication, in the discourse, to view, discuss'.
b. Simplification. 'Sometimes you want to make a model to explain something. You make a simplified version because the full reality is too difficult to explain, then you extract a lot from it until it becomes understandable'.
c. Reasoning and prediction tool. 'A more active aspect of modelling is that you can reason with it and experiment with it' and that 'we can use models as a tool to draw conclusions from'; 'not necessarily in the sense of predicting the future. But predictive within the meaning of that you extract expectations from it that go beyond what you had already seen. Expectations about how it works, expectations about how it became this way, or expectations on how to proceed'. This function can be divided in a theoretical and a practical part:

    - Theoretical trying out: 'At the moment that you want to get a picture for yourself about how reality works – so then is it really a conceptual model, you might say –, a construct to try to map out the reality. And then you have to omit things because otherwise you get distracted by too many things'. Another expert says: 'A model is a tool for reasoning […] it is a tool to think with and to generate new expectations or new ideas about how something works'. Furthermore it was said that models are used 'to make more insightful what is going on inside the head'.
    - Practical trying out: 'There are also models with which you can manipulate reality. These are mainly the dynamic models of course, with which you can simulate things. Which is actually the same function again as trying out how reality works; but not so much by thinking about it but by trying things out'. Furthermore, 'models allow you to make certain predictions'.

B. Gilbert's Definition

> *A model is a simplified representation of a system, which concentrates attention on specific aspects of the system. Moreover, models enable aspects of the system, i.e., objects, events, or ideas which are either complex, or on a different scale to that which is normally perceived, or abstract to be rendered either visible or more readily visible (Gilbert, 1995; Ingham & Gilbert, 1991).*

Concerning Gilbert's definition two questions were asked:

1. Do you agree with this definition?
2. Is there anything you miss about this definition?

Agreement with this definition
One of the experts agrees fully with Gilbert's definition, stating 'I cannot say anything against it' and 'that everything is in it', although 'it is very long'. All the other experts state that they do not (fully) agree with Gilbert's definition. Distinct parts of the definition were appreciated by the experts, such as the fact that the term *representation* covers many types of models and that important reasons to use models are described by the phrase "which are either complex, or on a different scale to that which is normally perceived, or abstract…" .
Besides the points on which the experts agreed with Gilbert's definition, the experts also pointed out what they would like to change in this definition:

- Models are used in more ways (n=3). According to some of the experts, 'the emphasis here (Gilbert's definition) is on making things visible'. This is especially visible in the first sentence: "A model is a simplified representation of a system, which concentrates attention on specific aspects of the system". Multiple experts point out that models are used in a broader context. They are not only used to visualize, but they are also used (or 'make it possible to') 1) 'to draw conclusions from' (n=1), 2) 'as thinking aid to come to new expectations and ideas about mechanisms of a system' (n=1), and 3) 'to be able to predict certain things (n=1)'.
- Phrase "aspects of a system" not well chosen (n=3). Several experts commented on the phrase "aspects of a system" and the term "aspect". It was said that the 'objects, events, ideas' mentioned in the second part of Gilbert's definition 'are in itself already systems' and if "objects, events" and "ideas" all fall under the term "system", then the meaning of the word system has become a bit meaningless: in that case everything is a system and then you might as well say that the reality is a system'. On the other hand it is also mentioned that 'the term system is unclear', questioning 'if you even determine ideas as part of the system, then what exactly is the model?', but also: 'if you have something that consists out of one piece, is it then a model?'. One of the experts states 'that you can also model things that do not necessarily have a systemic nature', because 'in the word system already captions the attention for that everything is connected and that is not always what you model, sometimes you are interested in something else'. Some of the experts argue that it therefore would be better if we do not call it 'the representation of a system', but 'the representation of the reality', so 'replacing *system* by *reality*'.
- It can also be complex, different scale AND abstract (n=1). One of the experts does not agree with the following part of the definition: "which are either complex, or on a different scale to that which is normally perceived, or abstract…". The expert points out that 'complex can also mean that it is abstract. Complexity can also be in the abstraction […] and if something is not visible, it can also be abstract or complex'.

- ‘Ideas’ should be replaced by ‘assumptions’ (n=1). One of the experts sees “ideas” as ‘ideas that people have about how things could develop’. In that case, he says, ‘these (ideas) are assumptions’. He suggests changing “ideas” to “assumptions”.

Missing in Gilbert’s definition
After asking whether the experts agreed with Gilbert’s definition, some already pointed out some things they missed in this definition. Besides, it was also specifically asked if they missed anything in the definition. Only one of the experts stated that he did not miss anything. The other experts named several things they missed. These will be presented below.

- Context (n=1). It was stated that ‘it is described without a certain context in which it plays a role’. According to one of the experts, whether a ‘model can actually function as a model, depends on the context’: ‘it does not make sense to define models without denoting what you do with it and where (you use it)’.
- Purpose (n=3). As part of the context, multiple experts missed ‘the purpose’. One of the expert argues that it is important that the function is described, saying that ‘it (a model) is about certain aspects and not about everything’ and that ‘this is closely interrelated with the function it has.’ According to the expert, ‘it is the specific function that a model has, that makes certain aspects important’ and that because of this, ‘other aspects can be left out’.
  It was suggested to add “for some purpose or function” to the current definition, changing the sentence to: “…which concentrates attention on specific aspects of the system <u>for some purpose or function</u>”.
- Function (n=2). Besides missing aspects of the purpose, some of the experts also missed ‘what you do with a model’: the ‘operational aspect’. The experts point out that models do not ‘just have a representative function’, but that ‘you can do something with it’ and that ‘therefore there is an active role for the model in the thinking process’. Examples given for how it can be part of the thinking process are that ‘models can be used to reason or to experiment’.
- Relationship between the elements (n=1). Besides the different context elements that are missing according to the experts, it was also mentioned that a reference to ‘the relation between the elements’ is missing:

> *‘It is a lot about the aspects of a system. So you could say: the aspects of the system are the elements and the relations and the coherency. […] but it is not very explicit, that that is what it is about.’*

C. Closely Related Terms

Table 1 presents the answers the experts gave on the question: which of these terms is closest to the term model in terms of meaning?

Table 1
Responses to the question 'Which of these terms is closest to the term model in terms of meaning?'

Concepts	n
Representation	8
Analogy	2
Image	
Metaphor	1
Paradigm	
Prototype	
Scheme	

Table 1 shows that the term *representation* was mentioned by all (n=8) of the experts, that the terms *analogy* and *image* were mentioned by two experts and that the terms *metaphor*, *paradigm*, *prototype* and *scheme* were mentioned by one expert each. The term *pattern* was not mentioned by any of the experts in response to the question and is therefore not presented in Table 1. The different concepts and their equality in comparison to the term *model* will now be discussed in more detail.

Representation
The most notable thing about the results shown in Table 1 is that the experts are about that there is great similarity between the term *representation* and the term *model*. The experts mention different similarities between representation and model. It was stated that 'a representation is […] a set of relationships between a system and the other system' and that a representation 'allows you to make something visible by any given situation that is otherwise difficult to get access to'.
What *representation* also has in common with *model* is that *representation* is seen as an "umbrella"-term for the other concepts included in this research. One of the experts says about this: 'I think that it (representation) is just the best term, because it includes all the other terms.' This means that a diverse group of terms and concepts can be categorized under the term *representation*.
That the term *representation* seems to have an umbrella-function in relation to the other concepts is also underlined by the fact that the experts mention for six of the concepts (*analogy*, *image*, *metaphor*, *paradigm*, *prototype* and *scheme*) that they are a kind of representation and that they can be a model, but do not have to be one.
But, even though the experts are positive about *representation* being the concept closest to *model*, there were also mentioned some differences. It was argued that what you see in a

representation ‘is very dependent on what you have learned and what you have been through and the context in which you show it and what you are doing with it at that moment’. Furthermore, it was stated that the term *representation* misses something ‘of the dynamic nature’ that models have and that a representation ‘is used when it is really about making something negotiable, or to look at it, talk about it, and making it visible in the communication, in the discourse’ where with models ‘it is about the relations and about drawing conclusions’. In the last case, it was noted that ‘there can of course be an overlay’.

Analogy

The terms *analogy* and *image* are second closest to the term *model*, both chosen by two experts (Table 1). As already mentioned in the paragraphs above, ‘an analogy can be a model, but not every analogy is a model, and also not all models are analogies’. However, one of the experts commented the opposite: ‘It is for me not really a model. I see… I experience a model really as a material object, a material representation of the object itself’.

Even though there is discussion about whether analogies can be models or not, most experts (n=7) agree that an analogy is ‘a possible relationship with reality’, used in ‘comparing the model with reality’. One of the experts adds that in making such a comparison, ‘you always look at what aspects of reality you put in your model and what you leave out of it’.

Another similarity between the concepts is that using them (*analogy* or *model*) ‘you can draw the attention to, for example, the functioning. So you accentuate the aspects that you think are important’. A downside of this aspect that was given is that ‘the observant will see a whole lot more things in that analogy that do not apply to what you want to… what it is all about’, since it is unclear ‘when it (the analogy) starts and when it stops’.

A difference between *analogy* and *model* that was named, is that the term *analogy* is ‘more (a term) from linguistics’ and ‘much vaguer’ then the term *model*.

Image

The concept *image* is, just like the concept *analogy,* chosen as being close to the term *model* by two experts (Table 1). It is one of the many concepts that ‘is a kind of representation’. It is however underlined that this does not mean that it is ‘necessarily a model’. According to one of the experts this is because ‘it could also have been drawn differently. […] One can make different images of one and the same model’. Others state that an image is ‘almost the same as a representation’.

The similarities that the experts see with models are that an image ‘is in fact a possible relationship with reality’ and that ‘in the image, things are accentuated that the maker thinks are vital’. However, the experts also pointed out some difference. First of all, images are said to be ‘static’ instead of ‘dynamic’. Furthermore, it was pointed out that an image is ‘two dimensional’.

Metaphor

Metaphor is together with three other concepts (*paradigm*, *prototype*, and *scheme*) chosen once as being closely related to *model* (Table 1). Just like most of the other concepts discussed so far, it was said that ‘a metaphor is a representation’.

Multiple experts point out that the concept *metaphor* is much like the concept *analogy* and that ‘the same argumentation can be used as for analogy’: it is also seen as ‘a possible relationship with reality’, used in ‘comparing the model with reality’, it is also ‘more (a term) from linguistics’ and it also has the danger that ‘the observant will see a whole lot more things’ in it ‘that do not apply to where it is all about’. It was furthermore mentioned that a metaphor is not dynamic and ‘says nothing about the future’.

Paradigm

Paradigm is, just like *metaphor,* chosen by one expert as one of the terms closely related to the term *model* (Table 1). One of the experts says that 'you can call it (a paradigm) a representation', since 'paradigm is a construct of the mind'. Furthermore it is stated that 'a paradigm is also a kind of a model, but with a different meaning. A paradigm is a kind of model that a group or field has as "core model"'. It was also stated that paradigm is used in the meaning of 'a paradigmatic example'.

However, it was besides said that *paradigm* 'does not fit in at all' and that it 'is a little bit strange'. Those experts argue that 'when thinking of a paradigm one thinks more of the bigger picture, how people think about things': 'it is more like the complete system of how one thinks of knowledge, or ones discipline', which is 'not on the same scale as model'. One of the experts adds to this that a paradigm is a 'social construct […] a socially transferable image of what things should be like' that is found 'in a group of people', and 'not an individual conceptualization of reality'. This is in contrast to model which 'can be used on any unit'. Furthermore, it was said that *paradigm* is 'a pretty static term. It is something that is in the head, and that is what it is'. 'One already knows what is going to happen'. This is said to be in contrast with models, because 'with a model you do not exactly know which way it will go.'

Prototype

The concept *prototype* was also mentioned by one of the experts as being close to the term *model*. The experts ascribe two different meanings to the term *prototype*. First of all, it is seen as 'a first exemplar of something, a prototype that still has many failings. A show model of something' used to 'see if all functions are in it' and 'to show others: this is what it is going to look like'. It is mentioned that this meaning ascribed to *prototype* is strongly associated with engineering. About this, one of the experts says: 'engineering is basically always not about the reality that already exists – that is where science is about –, but about the reality as it has to become, as we want it', or, as someone else puts it: 'it is a step in the design process towards the real thing, or the finished product'. It is pointed out that a *prototype* – being part of a design process – has 'a more realistic character' than *model*.

The other meaning ascribed to *prototype* is that of a "prototypical model": a kind of model in which 'you try to catch different kinds in one', and a kind of model 'that is presumed to represent the essential characteristics'. Similarities found between this kind of *prototypes* and *models* are that 'you have to make assumptions […] about what is essential and what is not', and that based on the right assumptions it has 'explanatory power'.

Scheme

Another concept that was mentioned by one of the experts as being close to the term *model* is *scheme*. The experts say that 'a scheme is a representation', it is 'a specific form of representing' and it 'can also be a model'.

Besides this association of *scheme* with being a kind of representation, multiple experts pointed out that they also associated *scheme (*or *schema)* with psychology. One of them mentioned that 'according to many psychologists, you do also have internal schema's, about how you do certain things and in what order, habits'.

Although it is pointed out that 'schema comes from psychology', the experts also see it as 'an image with vectors and arrows et cetera'. Similarities that are named in comparison with *model,* are that *schemes* are also used 'to make something visible in a certain situation that is otherwise hard to get access to', 'to draw attention to certain elements', and 'to show the relations between the different elements' and 'highlight the coherency'.

Pattern

The term *pattern* in absent from Table 1, because *pattern* is not similar to the term *model* (in the scientific context) and least like the term *model* of all the concepts that were presented to them according to the experts. One of the experts said that ‘you might be able to see it as a model when it is about a pattern like a dress or knitting a jumper’, however, it was emphasized that the term *pattern* was most of all seen as something ‘that can be visible ín a model’. One of the experts actually says about this: ‘I think pattern is actually a bit of an outsider’. This was backed up by statements like ‘a pattern is more the relation itself and not so much the model’. The experts describe patterns not as a model, but as ‘a pattern is a certain regularity, or structure’ that ‘has something repetitive’. Furthermore they say that patterns are ‘static’.

D. Learning Objectives

The main goal of this study is to find learning objectives for using and designing models in science, mathematics, and technology subjects in lower secondary education. These learning objectives have to be both *desirable* and *achievable*. Therefore, the experts were asked about what learning objectives are desirable according to them. Furthermore, after showing the experts a scheme with an overview of learning objectives, it was asked which of those they thought are desirable and achievable for lower secondary education. The results will be discussed in this section.

Desirable learning objectives
In response to the question 'what are desirable learning objectives for lower secondary education in terms of models and modelling?', the experts named several subjects and learning objectives about models that are important in lower secondary education. These will now we discussed.

Purpose and function
Multiple experts stressed the importance of students learning about the purpose and function that a model has: 'I would like to emphasize the purpose and function in lower secondary education in one way or another: the why of a model. So the "why" is in my opinion equivalent to a "purpose/function".' 'Just to become aware of the fact that there are multiple reasons for creating models and also to gain a bit for an understanding of: where do these models actually differ in?'
It was emphasized that as part of this, the students should have 'to understand that they (models) have a communicative function' and 'have to know about the role models play in the construction of scientific knowledge'.
It is furthermore mentioned that as part of the function of a model, it is important to teach the students 'the difference between descriptive and normative. […] So that they notice that some models just try to represent the current reality and that there are other models that give an idea of how it is going to be'.

Nature of science
Furthermore, a notion of the nature of science was emphasized: it is important 'that students realize what science actually is' and what scientists do:

> *I find it valuable that pupils in lower secondary education get a notion of what scientists actually do. […] To experience just a few times why these scientists are busy with what they do and what higher purpose is behind it.*

It was also mentioned that it is vital that students 'notice that a model is but a model; that it is a simplification of how it really is', that it 'is a representation of reality'.

Types of models
One of the experts says that 'they (the students) should know something about types of models'.
'That they are offered each kind of model that exists – maybe two, three times per domain – and that they should reason and work with those.'
Additionally, it was argued that it is essential 'to work with alternative models […] So when you want to discuss something: what is a good model?'.

Model as source of knowledge
One of the experts mentioned that it is desirable that ‘students learn with models’.
Another desirable way of using a model to gain knowledge is ‘using it (the model) to make predictions’ and ‘reasoning with, or by using, a model’. This is explained as ‘interpreting the model outcomes in the light of the terms you put in the model’.

Assumptions and limitations
It was mentioned that students ‘should be able – when they come into contact with a scientific model – to question the assumptions behind the model and the limitations of it: the borders’.

Nature of models
One expert stated:

> *I think it should start with the notion of the nature of the model, so that we create images of reality, simplifying reality in a certain way. So, that first all pupils realise that that is one of the things that we do both in science and in engineering.*

So, ‘the idea of abstraction; that you – by using a model – can focus on the elements and factors that matter, or the relationships that matter. By which you leave other things out’.

Making a model
Multiple experts point out that the students ‘need to have made models themselves’ in different contexts: students should be able ‘to create models by which they describe their own living environment and other types of contexts, such as professional contexts’ and ‘students should be able to create models with which they can make clear how they understand the scientific reality’. So ‘making insightful what is going on in their head, as a kind of modelling’.
Furthermore, it was mentioned that students should ‘at least once go through the design cycle’.

Responses to the scheme
According to the experts, none of the learning objectives in the scheme are *not* achievable. Some of the experts even say that *all* of the learning objectives are achievable, depending on two things: 1) ‘how complex do you make the model?’ and 2) ‘how complex is the object that you want to model?’.
How achievable a model is according to the experts does not automatically correlate with how desirable it is: the experts do not see every learning objective as desirable.
In Table 2 is shown how many experts talked about that a learning objective was desirable *before* they had seen the scheme with learning objectives and how many experts said that a learning objective was desirable *after* the scheme was presented. If an expert named a learning objective as desirable both before and after seeing the scheme, then this was only counted in the before column.
As can be seen in Table 2, there is a wide variety in how many experts think a learning objective is desirable; learning objective 5, 7, 9 and 14 being clearly least desirable, being chosen by only one expert each, and learning objective 10, 8, 15, 3, 6, and 11 often chosen as desirable: by 7, 6, 6, 5, 5, and 5 experts respectively.

Table 2.
An overview of how many experts talked about that a learning objective was desirable before *they had seen the scheme with learning objectives and how many experts said that a learning objective was desirable* after *they had seen the scheme.*

	Desirability* (n)		
Learning objective	**Before**	**After**	**Total**
1.	1	3	4
2.	-	4	4
3.	-	5	5
4.	3	1	4
5.	-	1	1
6.	3	2	5
7.	-	1	1
8.	4	2	6
9.	-	1	1
10.	1	6	7
11.	1	4	5
12.	-	3	3
13.	-	2	2
14.	-	1	1
15.	3	3	6

* If an expert named a learning objective as desirable both before and after seeing the scheme, then this was only counted in the before column.

Now, the comments of the experts on the different categories and the learning objectives will be described in more detail.

Learning with models
This first category consists of three learning objectives: 1) The student can use a model to gain knowledge; 2) The student can point out in a model used during the lesson in which aspects it is similar to and in which aspects it differs from reality; 3) The student can compare multiple models of the same phenomenon in what aspects of reality they show. These will now be discussed individually. General remarks on this category will also be discussed.

- Learning objective 1. Multiple experts pointed out that learning objective 1 is desirable, because it is important that students 'learn with models' and use models as 'an aid to gain knowledge'. According to one of the experts, models function as 'inference tickets' (referring to a statement by Camerer (1985) that "models are inference tickets"). Using a model 'is an intermediate step in reasoning or in a conclusion' and 'because of this, a model is actually a kind of inference ticket to be allowed to draw a certain conclusion'. However, not everybody agrees with this learning objective. Someone stated that:

  > *Models are the knowledge that you want to communicate, so "using a model to gain knowledge" is a kind of circle reasoning. [...] Much of the knowledge is cast in models. Therefore, a model is not just an aid, but a goal on itself.*

- Learning objective 2. The experts emphasize it is important that the students learn 'to what extent it (models) matches with and it differs from the reality', and that for example the colour of a model of a neutron does not have to be the actual colour, but depends on what the maker of the model wants to demonstrate with it.
  Another thing that was pointed out is how this learning objective includes the nature of science: 'the notion of the nature of the model, meaning that we make representations of reality, simplify these representations in a certain way' and that it is important 'that all students understand that this is one of the things that one does in both science and engineering'. However, it was also pointed out that models do not necessarily have to have any similarities with reality. The expert gives the example of 'computer-listing', 'which does not at all stroke with reality. It describes the expected reality'.
- Learning objective 3. The experts give different reasons why they see this as a good objective. First of all, it was stated that it is good that it 'reflects the goal-function', which shows 'that the model serves a certain goal'. Besides, 'making comparisons is very meaningful because it makes you see what is important and understand the structure'. Furthermore, it was pointed out that the objective displays that 'you can model the same reality in different ways', which 'is closely related to the nature of science: you use different theories to describe the same phenomenon'. In addition, one of the expert says that 'they (the students) should know about types of models, and I do not necessarily mind whether the tripartition of Nauta and Bertels (1969) or another one'.
- General remarks. There are some general remarks on the learning objectives in this first category. One of the experts 'has trouble with the term "reality": […] Maybe you can replace "reality" here by "perception", or something. That is important. You perceive things. And you make models that can explain or with which you can understand what you perceive'.

Learning about models in education
This second category consists of four learning objectives about learning about models in education: 4) The student can specify what the functions are of models in education; 5) The student can specify features of an educational model; 6) The student can explain what conclusions can and cannot be drawn from a model in education; 7) The student can assess which models are suited in a given learning situation. These learning objectives will be discussed individually, together with the general remarks on this category.

- Learning objective 4. This learning objective is valued by multiple experts, because it says something about the 'purpose and function' and 'the why of a model'. Or, as one of the other experts formulates it: 'when you do not understand the function, then you do not understand at all what the model does. Then you do not understand the model at all'.

However, it was argued that for this reason ‘one should not have to “specify” what the function of a model is’. Instead, the importance of “understanding” the function of models is pointed out.

- Learning objective 5. About this learning objective is said that how desirable and achievable it is depends on what is meant by “feature”: ‘Look, if you by feature mean “it is a simplification”, then I think it is a perfectly achievable learning objective. If you want to do more, then it might be a bit more difficult’.
- Learning objective 6. According to one of the experts, this learning objective ‘is important, whether you work with a model created for your educational situation or a scientific model that is actually used in science’. Students must not only be able ‘to explain what conclusions can and cannot be drawn from a model in education’, but from ‘every model’.
  Another expert agrees with this and adds that this learning objective can be seen as part of the process of modelling, ‘especially when you do not limit which conclusions can and cannot be drawn from a model to educational models, but also include scientific models’. Besides criticism on the limiting effect of the phrase ‘model in education’, it is also argued that ‘not every model is meant to draw conclusions from. So therefore this objective only counts for models where conclusions arise from’.
- Learning objective 7. Although the experts stress the importance of students getting ‘a kind of feeling for that it is not the case that one model is true and the other is not, but that depending on the goal you have, you choose a model’, the main remark on this learning objective is that it is ‘more seen as a teacher-objective. He/she should make the decision, like: I will use this model in the classroom’.
- General remarks. Multiple experts remark that they would remove “in education” from “a model in education” in this category. Some even suggest ‘to completely delete the complete “in education” column’.

Learning about models in science (NOS)
This third category consists of four learning objectives about models in scientific research: 8) The student can specify what the functions are of models in research and professional practice; 9) The student can name features of a research model; 10) The student can discuss the limitations and accuracy of a model; 11) The student can assess which models are suitable for a particular phenomenon to investigate. These will now be discussed individually. There are no general remarks made on this category.

- Learning objective 8. Many experts are positive about this learning objective: ‘I find 8 very important. (…) There is done a lot of modelling in the practices. And I find that students need to know that’. Someone else says that ‘they (students) should know something about the role models play in the construction of scientific knowledge’. However, some are a bit more sceptical: ‘I wonder if students in class 1 and 2 (on average students from 12 to 14 years old) look and can look this far ahead’ (to research and professional practice).
- Learning objective 9. It was pointed out that being able to ‘“name” the features of a research model’ is ‘quite difficult for them (the students)’ and ‘not relevant’. The experts state that one should not want the students to ‘only naming characteristics, reproducing those characteristics’. Instead, it is argued that students should use these characteristics in a more relevant context: ‘you have to be able to do something else with it (the characteristics). So the objective must not be about the characteristics that a model has, but about what you can do with it’.
  Furthermore it is argued that this learning objective should not be limited to research

models, but to ‘models in every professional practice’. Also, it was stated that ‘the features of the design model could be facing the features of a research model’, something that now is ‘still missing’.
One of the experts missed ‘a process that belongs to learning about models’ in the learning objectives. This process however, can be seen as a characteristic of a research model. He describes this process as following:

> *The historical aspect of knowledge development by model, and a model is not up to par and then the debating starts. New ideas arise for a new model, for years there will be arguments about it and then arises a new, dominant model.*

- Learning objective 10. This learning objective was called part of the ‘nature of science’: the ‘limitations’ of a model are seen as an ‘essential’ part of ‘the nature of models, the difference between model and reality’. Plus, it takes into account that models have their limitations, since ‘some things just cannot exist. Not physically or chemically’.
  It was also stated that:

  > *You assess or evaluate a model on the basis of certain criteria: […] goodness of fit, validity, reliability, and there are a few other criteria that you can use to study the quality of a model. No, not to study: to value. I think in higher secondary education such a learning objective certainly is necessary. And in lower secondary education you could maybe insert one or two of those criteria. As pupils work through modelling cycle, they should have to value their final product, their model.*

  One of the experts says that the students should ‘most of all be able to question the limitations/borders of, and assumptions behind, the models they come into contact with’. Furthermore, suggestions were offered for expanding this learning objective. One of the experts says students need to learn to ‘reason with a model, or based on a model’ and ‘to treat it as a closed system’, and that therefore ‘the model outcomes that you get should be interpreted as a consequence of the assumptions you model’.
- Learning objective 11. One of the experts argues that ‘by assessing which model is suitable, you someway assume that you then also reasoned with that model and experienced that this model works better than that (other) model’. In an educational setting this could be done ‘by showing different kind of models and to ask: who fits well to whom? So it is a kind of matching assignment. […] so the students understand that a computer model and an (other) model are not the same’.
  One of the experts advices to change this learning objective to: ‘The student can assess which models are suitable for a particular practice’, so without “to investigate”. It was added that ‘this can be the research practice; this can be a professional practice’.

Learning to model
This last category consists of four learning objectives about the practice of modelling: 12) The student can suggest how the model can be improved; 13) The student can change (parts of) a model for a particular purpose; 14) The student can develop a model by combining components from more than one model; 15) The student can create simple models (through provided modelling software). These learning objectives will next be discussed individually. There were made no general remarks on this category.

- Learning objective 12. Although some of the experts call this objective ‘excellent’ and ‘functional’, others argue that there are some dangers in the word “improved”. One expert sketches this with a scene of students' modelling:

> *Well, improvements… That is something they (the students) find quite hard. What they then do – and that is something very frustrating -, is that they say: well, there are a lot of factors that are not in it (the model)'. I say: well, put them in there'. And what you see then, is that the model becomes incredibly complicated. […] So the trick on one side is to get a realistic model and on the other hand you have to strip is so far, that it is not terribly complicated.*

- Learning objective 13. It was stated that this learning goal is on another level, because 'students find out that once a model is designed – regardless the function or purpose -, it is not unchangeable. That is something that will be hard for the students to accept; that things can change'. Another positive aspect of this learning objective is 'that it makes you think about the purpose of a model'.
  A point of criticism is that:

  > *The purpose is quite determining for the model. So that means we are having a logical problem. […] It is strange to say 'if you change the purpose, then you have to change the model". No, then you have just a different model.*

- Learning objective 14. This learning objective is called 'quite abstract' and 'not very desirable for a student'. Someone else says that the act of 'combining components […] is something that you actually do all the time when modelling. So it is already ín modelling, that you combine, change…'
- Learning objective 15. Experts point out that this learning objective is desirable for lower secondary school and 'that they (the students) must have done that at least once'. One expert suggests that 'as a "stepping stone", it might be a good idea to start with qualitative modelling'.
  However, by others it was pointed out that to "create simple models" it 'is not necessary' to do this 'through provided modelling software'. For example, 'you might as well create a simple model by clay modelling'.
  Furthermore it was claimed that learning objective 15 is desirable 'because in 15 is the complete modelling cycle represented'. However, another expert argues that the 'modelling cycle', should be 'specified explicitly'. For example 'the student can name the stadia of the development of models, something like that'.

Suggestions for improving the scheme
In order to be able to improve the scheme with learning objectives that was presented to the experts, there was specifically asked for the experts' opinion on the layout.
Most of the comments were about the column "in education". According to multiple experts 'the whole column can be deleted' or 'combined, synthesized, made to one column "learning about models"' (combined with the "in science" column). About this is said:

> *I would call it (in the learning objectives) just model – features of a model -, and of course this is about education: it says so on top. […] I think it is just a model that is used in science. […] So I think it can be just in general. […] So the focus on education… I do not quite see why a student has to know that.*

Another thing that is said about these two columns is that 'these are not so much different models, but they are used in a different context'.

It was also mentioned that ‘you also make models when designing. […] I understand that students learn what functions models have in research. And in the same way I would like students to see what kind of role models play in design’.
Furthermore, some of the experts say that they ‘would bring something of a model cycle in it’, ‘the complete cycle of steps’. Someone mentions that ‘scientific practices are also professional practices’, and there are remarks about the inconsistency in headings (‘models, models, modelling’) and advises to change it to ‘learning to design/develop models’. Besides, there was one expert who argued that there are ‘two main learning objectives: 1 and 2 […] and then all the others can be filed under it’.

E. Features

The experts were asked their opinion on the eight general features of scientific models as described by Valk, Driel and Vos (2007). These are the features that learning objective 5 and 9 refer to.

Features that the students need to know
In Table 3 are the answers on the question 'Which of these features do the students have to know at the end of lower secondary school?' presented.

Table 3
Responses to the question 'Which of these features do the students have to know at the end of lower secondary school?'

Feature	n
2	7
1, 3	5
4	4
5	3
6, 7 , 8	2

The Table shows that there is not unanimity about one of the features, although a majority (7 out of 8 experts) stated that students in lower secondary school should learn feature 2. Feature 1 and 3 are also named as desirable by a majority of the experts (5 out of 8 experts). What is furthermore striking is that – feature 2 excluded – the higher the number of the feature, the fewer the experts think this feature should be known by the students at the end of lower secondary education.

The experts' view on the features
The experts explained why they did or did not agree with the features presented. An overview of the remarks will now be given.

- Feature 1. According to the experts, 'the distinction between model and object is of course really a basis; you cannot get around it'; 'it describes how natural sciences deal with models that are intended to serve scientific research'.
  However, one of the experts argues that "There is a strict distinction" is 'not a feature of a model'. Although the expert agrees with the statement, it was stated that 'it is just the distinction between model and object. […] It does not say anything about the feature of a model'.
- Feature 2. This feature 'describes how natural sciences deal with models that are intended to serve scientific research'. It was stated that 'students should be able to use feature 2, because it captures the essence of the use of models in science. Feature 2 reflects the

value'.

- Feature 3. About this feature is said 'that it describes how natural sciences deal with models that are intended to serve scientific research' and is called 'a very important feature', since people 'in the natural sciences of course love hypotheses'. According to one of the experts 'a model is in fact a hypothesis'.
  However, there is also criticism on feature 3, especially on the first part of it (3a). One of the experts stated that models do not necessarily have anything in common with the object of research. 'In physics, you work with rules and based on these rules you make a model. However, these rules are not reality'.
- Feature 4. Just like the three prior features, this feature 'describes how natural sciences deal with models that are intended to serve scientific research'. And, just like on feature 3, criticism on this fourth feature is that 'a model is a model. So it differs in all respects from the target. Because it is something different, it is a different thing'.
  Some of the experts agree with this feature, because 'you cannot represent all aspects of the object of research. Those are these differences (mentioned in feature 4). That also makes it more attractive, because you work on a less complicated system then your original system'. Another expert says about this: 'the reality is simply hard to tackle, so therefore a model can be more attractive for research'.
  Another expert says that 'number four is a bit vague'. It was argued that:

  > *What I think it is about is that there are certain similarities that matter. And differences do not matter. So to say that the differences make the model more attractive for research, that is in my opinion a bit of a wonderful formulation.*

- Feature 5. According to experts this is the last of the five features that 'describes how natural sciences deal with models that are intended to serve scientific research'. One of the experts says 'a model is always a compromise' and that this 'makes it more attractive, because you work with a less complicated system then the original system'.
  Another expert says "I do not agree with feature 5. I just drew a model and I do not have the feeling that I had to compromise or that I had to deal with contradictory demands'. It was also stated that 'you can make models on different levels, which makes feature 5 a little bit vague'.
- Feature 6. According to one expert this feature 'has another nature then the former five: it is not a feature. It is a particularising of models'.
  It was furthermore stated that:

  > *It is good that it mentions that a model requires creativity. A model is a construct; you do not derive it from reality. [...] So it are human constructs, they require creativity. And there is a similarity with designing, because that of course requires creativity too.*

  Besides, 'it (modelling) is a lot of fun to do, and that the students like it too because it leads to a result'.
  It was also mentioned that:

  > *Feature 6 is interesting because it says "construction" and names the purpose. For me, if you start with that, the rest will come after that. [...] So I guess I would focus on that, if you emphasize these two aspects ("having analogies with" and "being different from") in lower secondary education, then the students will also notion the other things.*

- Feature 7. This feature is also said to be ‘a particularising of models […]; a phenomenon that occurs in the natural sciences’. However, it was also said that ‘students should be able to use feature 7, because it captures the essence of the use of models in science. Feature 7 is about the truth status of models’.
  The experts point out that ‘the strong part of feature 7 is that it shows that you use different models in relation to for example the same object’, because ‘students often have the idea that theories just arise from your data. And that is not the case; they are constructs. That is why you can make multiple models from the same data’. Furthermore it was said that ‘the good thing about the term “consensus models” is that it depicts that models are something that we make; that these models are created in a certain context’. One of the experts says:

  > *It says here “depending on the precision requested”, I think this can be broader, dependent on the requested function maybe or dependent on a certain target group. If I explain something to elderly people I might make another model then I would make for children, even though it is about the same reality.*

  Furthermore ‘it is also a case of what phenomenon you want to describe’, and which model is the best ‘does not only depend on the precision requested, but also on the perspective on the system. You can also describe a very simple system in two different ways’.
- Feature 8. Just like the two former features, this feature is seen as ‘a particularising of models. […] it says “can” so then it is not a fixed feature’. However, it is also argued that ‘you can almost leave the word “can” out. Models always have an iterative character. You always try to improve the next step’.
  Another expert says:

  > *The iterative character is also something characteristic. […] I do not know if it is characteristic for all models, but it is definitely something that plays a role in mathematics, especially when it is about the role of such a model in a learning process.*

  Besides, it was stated that – just like feature 7 -, ‘students should be able to use feature 8, because it captures the essence of the use of models in science. It is about the truth status of models’.

Conclusion

The aim of this study is to get a better view on what we want to teach students in lower secondary education. Therefore, the main question of this research is: What are desirable and achievable learning objectives for using and designing models in science, mathematics, and technology subjects in lower secondary education?
In order to be able to formulate desirable and achievable learning objectives, first the meaning of the term *model* and related concepts need to be clarified. The first pieces describe the experts' view on this. Based on this, and on the selection and additions that the experts made, learning objectives can be formulated.

The term model and related concepts
This descriptive study shows that the most common meaning ascribed to the term *model* by the interviewed experts is that of a *representation of something* that has *a certain purpose and function* and *a role in a certain context*. Three function-groups are named (visualisation, simplification, reasoning and prediction tool) and four different contexts are mentioned (social, professional, scientific and educational). The different entities that are named for the *something* in this definition are: events, ideas, objects, and processes. Those entities together make out the *reality* that a model describes.
Based on the experts' definitions and their answers on specific questions about Gilbert's definition, Gilbert's definition can be used as a definition for models in science education, as long as the former discussed identified conditions are incorporated. Furthermore it is by the experts underlined that the term "system" might be better changed to "reality", that models are not necessarily "complex, different scale OR abstract", but can also be "complex, different scale AND abstract" and that the definition misses a reference to the relationships *between* elements.
In relation to the closely related terms it can be concluded that there is one term in particular that is in meaning very close to the *model*; namely *representation*. The experts are unanimous in that there is a great similarity between the concepts. However, the concepts cannot be used interchangeable: *representation* is mainly used in the context of 'making something visible', where *model* is used in a variety of contexts and has more functions then just visualising. The purpose, function and context that a certain model has, are seen as part of the model, where a representation is seen as the "representation"-part of the model: so the model *without* its purpose, function and the context in which it functions.
Based on the above, the meaning of the term *model* for educational purposes can be described as follows: *A model is a representation of an event, idea, object or process that has a certain purpose and certain functions in a certain context.*
In this definition, *purpose* is a goal to be reached, and *function* is what something does or is used for. For example, a model made with the *purpose* of giving insight in the process of photosynthesis, can be *used* as explanation tool to teach students about photosynthesis.

Desirable and achievable learning objectives
The main goal of this research is to identify what are desirable and achievable learning objectives for learning about and with models in science and technology subjects in lower secondary education.
According to the experts, none of the learning objectives that were shown to them are *not* achievable. Some of the experts even say that *all* of the learning objectives are achievable, depending on two things: 1) 'how complex do you make the model?' and 2) 'how complex is the object that you want to model?'.

Table 4 shows how many experts say that a certain learning objective was desirable. In the comments-column, for each learning goal a summary was given of the most characteristic comments.

Table 4.
The learning objectives with the amount of experts finding them desirable and their main comments.

	Learning objective	Desirability (n)	Comments
1	The student can use a model to gain knowledge	4	Using a model 'is an intermediate step in reasoning or in a conclusion' and 'because of this, a model is actually a kind of inference ticket to be allowed to draw a certain conclusion'.
2	The students can point out in a model used during the lesson in which aspects it is similar to and in which aspects it differs from reality	4	'It should start with the notion of the nature of the model: that we make pictures of reality, that we simplify in one way or another. So that students realise first that that is one of the things that we do both in science and engineering'.
3	The student can compare multiple models of the same phenomenon in what aspects of reality they show	5	It is 'very meaningful' to 'make comparisons' and to understand that 'you can model the same reality in different ways'. 'They (the students) should know about types of models'.
4	The student can specify what the functions are of models in education	4	'One should not have to "specify" what the function of a model is'. Instead, "understanding" the function of models is underlined.
5	The student can specify features of an educational model	1	How desirable and achievable it is depends on what is meant by "feature".*
6	The student can explain what conclusions can and cannot be drawn from a model in education	5	This learning objective can be seen as part of the process of modelling. The main criticism is that students must not just be able 'to explain what conclusions can and cannot be drawn from a model in education', but from 'every model'.
7	The student can assess which models are suited in a given learning situation	1	This learning objective is 'more seen as a teacher-objective'.
8	The student can specify what the functions are of models in research and professional practice	6	'They (students) should know something of the role models play in the construction of scientific knowledge': 'Just to become aware of the fact that there are multiple reasons for creating models.'

9	The student can name features of a research model	1	Just like learning objective 5, how desirable and achievable this learning objective is depends on what is meant by “feature”.* It was stated that instead of ‘only naming the characteristics’: ‘you have to be able to do something else with it (the characteristics). So the objective must not be about the features that a model has, but about what you can do with it’. Besides it is argued that this learning objective should not be limited to research models, but to ‘models in every professional practice’.
10	The student can discuss the limitations and accuracy of a model	7	The ‘limitations’ of a model are seen as an ‘essential’ part of ‘the nature of models, the difference between model and reality’.
11	The student can assess which models are suitable for a particular phenomenon to investigate	5	It is essential ‘to work with alternative models’, ‘they (the students) should know something about types of models’: ‘this can be the research practice; this can be a professional practice’. Besides, it was suggested to remove “to investigate”.
12	The student can suggest how the model can be improved	3	There are worries about the word “improved”: ‘the trick on one side is to get a realistic model and on the other hand you have to strip it so far, that it is not terribly complicated.’
13	The student can change (parts of) a model for a particular purpose	2	‘Students find out that once a model is designed – regardless the function or purpose –it is not unchangeable. That is something that will be hard for the students to accept; that things can change’.
14	The student can develop a model by combining components from more than one model	1	This learning objective is ‘not very desirable for a student’ and ‘combining components […] is something that you actually do all the time when modelling. So it is already ín modelling, that you combine, change…’
15	The student can create simple models (through provided modelling software)	6	In this learning objective, ‘the complete modelling cycle is represented’. However, it is argued that the ‘modelling cycle’, should be ‘specified explicitly’. Furthermore, it ‘is not necessary’ to create simple models ‘through provided modelling software’: there are other options. It is suggested ‘to start with qualitative modelling’. Besides, students should be able to make ‘insightful what is going on in their head, as a kind of modelling’: ‘to create models by which they describe their own living environment and other types of contexts, such as professional contexts’ and ‘to create models with which they can make clear how they understand the scientific reality’.

It can be concluded that the following learning objectives are most desirable according to the interviewed experts:

1. (10) The student can discuss the limitations and accuracy of a model.
2. (15) The student can create simple models.
3. (4/8) The student can understand what the functions are of models.
4. (6) The student can explain what conclusions can and cannot be drawn following a model.
5. (11) The student can assess which models are suitable for a particular phenomenon.
6. (3) The student can compare multiple models of the same phenomenon in what aspects of reality they show.

These learning objectives include the suggested changes for learning objective 2 (formerly learning objective 15), 3 (4/8 combined) and 4 (6).
Learning objective 5 and 9 (being able to specify features of a model) are not desirable according to most of the interviewed experts in the current general form (see Table 4). However, when asked about the features of the eight general features of scientific models as described by Valk, Driel and Vos (2007), it showed that some of the more specific characteristics are important to teach the students according to the experts; the most popular features being feature 1, 2 and 3.

Discussion

Methodological limitations

Before saying anything about how the findings of this research are related to findings of other authors, some methodological constraints need to be discussed.

Selection of interviewees
The main instrument of this research was a semi-structured interview. The interview plan can be found in Appendix 1.
Eight experts were interviewed. All of them had a background in educational research, in one of the science, mathematics, and technology disciplines (at least one researcher was interviewed for each subject described in the *Kennisbasis*), and were familiar with research about models in science education. Since the semi-structured interviews are applied to just this cohort of participants, the outcomes of this research cannot be generalized to the entire population. The goal of this research, however, was to get insight in what people with a more grounded view on and knowledge about models in science and education think about what students have to know about models and how they should be able to use models. This, in contrast to all the studies conducted on how students and teachers see models and how they see the nature of model. Therefore, this study shines a new light on the topic and describes the views of a different field.
Nonetheless it is important to keep in mind that the specific background of the interviewees very likely led to a bias of results (and even more so because most of the participants work in the same institute); people with a research background are likely to have e.g. a bias towards models in science (nature of models, nature of science and modelling) and therefore might have a different view on the study subject in compared with teachers without a research background or educational researchers in another field of discipline.

The interview
During the interview, questions were asked about a scheme with learning objectives. Learning objectives from several educational research literature and educational curricula were placed in a scheme. By doing this, it was aimed to give a complete overview of possible learning objectives concerning models and modelling that were general enough to be used in the different subjects.
It is important to keep in mind that the scheme presented to the experts is based on a selection of literature. Besides, in order to organize some consistency, these learning goals were further selected, combined, abstracted and rewritten. This makes it possible that (some of) the learning objectives in the scheme have become too general or that certain learning objectives are lost in the process.
It was intended to overcome this problem by asking the experts about what they thought were desirable learning objectives before they had seen the scheme with learning objectives and by asking after showing the scheme about possible missing learning objectives. Furthermore, the structure of the interview made it possible for the expert to suggest additions to the scheme at any time during the interview.

Data-analysis
During the official interviews, it was discovered that one specific question was missing from the interview plan that explicitly addressed which learning objectives from the scheme are

desirable according to the interviewees. This means that this question was not asked in all the interviews. Nonetheless, when analysing the interviews, this answer could partly be derived from other questions: 4a. ‘What learning objectives on models do you think are desirable for lower secondary education?’ (before seeing the scheme) and 4b. ‘Where can you find your learning objectives in this scheme?’ and 4d. ‘Are there other learning objectives you think are important for lower secondary education?’ (both after seeing the scheme). Besides, multiple experts started – after having studied the scheme – about what they thought were the important learning objectives before they were even questioned about this. Based on this, it was still possible to show to analyse what learning objectives were seen as desirable. A second coder analysed this part of the interview and the differences were discussion to come to one answer.

Relation to prior research

A. Nature of Models

Nature
Most of the experts (7 out of 8) expressed their view that ‘a model is a representation’. This corresponds with the findings of Justi and Gilbert (2003), where ‘all the teachers expressed this idea’. Furthermore, Justi and Gilbert (2003) identified that some say ‘a model is a representation’ of ‘a whole’ and some that ‘a model is a representation’ of a ‘part’. This was also visible in this study: some of the experts said it was a representation of reality (‘a whole’), some named a ‘part’: ‘an object/process/idea’, ‘a process or phenomenon’, and ‘a certain structure or pattern’.
One of the experts called a model ‘a hypothetical description of reality in terms of a set of rules, which follow expectations about what could happen in reality’. This is a category of meaning that is not described by Justi and Gilbert (2003).
None of the experts interviewed in this study explicitly expressed the two other categories of meaning Justi and Gilbert (2003) (‘a model is a reproduction of something’ and ‘a model is a mental image’) when asked about how they would define the term *model*.
However, that none of the experts in this study stated that ‘a model is a reproduction of something’, corresponds with the findings Justi and Gilberts (2003), who found that this was predominantly expressed by the fundamental teacher group (teaching students aged 6–14 years), and a lot less expressed by the other groups (medium teachers teaching students aged 15-17 years, student sciences teachers and university science teachers).
In their research, it further shows that many teachers associate ‘models’ with ‘mental image’. Although the experts in this interview did not explicitly define models as mental models, some of them stated that *schema* has a lot to do with mental models and as one of the experts pointed out: ‘Human operating is only possible on the basis of a model of your surroundings […] and your ideas on how people function, can – from a psychological point of view – all be considered as models’. Therefore it can be said that in this study, also an association between ‘models’ and ‘mental image’ was found.

Entities
From the interviews, four different entities could be identified: events, ideas (also: ‘theories’ or ‘thought experiments’), objects, and processes. This also corresponds to the findings of Justi & Gilbert, who found the same entities.

Use
Justi and Gilbert (2003) describe four different uses of models. Three of them can be matched with the uses of models found in this study:

- Visualisation: ‘A visualization, enabling a person to ‘see’ a phenomenon’
- Simplification: ‘A way of understanding or explaining something’
- Reasoning tool: ‘A way of supporting creativity, the imagining of new contexts and the creation of new ideas’

The fourth use described by Justi and Gilbert (2003) is ‘a standard or reference to be followed’, which is not named by the experts in this study (this is also less expressed by he interviewed teachers in the study of Justi and Gilber (2003) then the other three uses: 49% relative to 87% (visualiszation), 87% (creativity), and 92% (explanation).
Besides, Justi and Gilbert (2003) do not identify ‘predicting’ as one of the uses of the model. Instead, they place this under the aspect Time (on “the stability of a model over time”). Here, they quote: ‘Scientific models are used to make predictions and they are changed depending on the outcome of those predictions’

Contexts.
The context is named as an important part of the definition of models. Many experts indicate that models are used ‘everywhere’, and more specific in social contexts, professional contexts, the scientific contexts and educational contexts. It was pointed out that if we want to give students a realistic view of model use, it is important to incorporate these different contexts in education and to not stick to model use in science alone.

B. Gilbert’s Definition
Two problems considering the terminology around the term *model* were addressed. The first one was that in the field of science, mathematics and technology education, there is not one unifying definition used to describe the term *model*. The experts were asked questions about Gilbert’s definition of models, to get an idea about what components are important to include in a definition about models and what should be excluded.
When asked about what a model is, most experts articulated that they say a model as a *representation of something* that has *a certain purpose* and *certain functions* in *a certain context*.
When comparing this to Gilbert’s definition, it can be seen that certain aspects in Gilbert’s definition are not reflecting this. This was also articulated by the experts after reading Gilbert’s definition. They state that the following things are missing or that the examples given are incomplete:

- a model serves in a certain context
- a model is created for some purpose
- a model has a function (more functions then that come forward in Gilbert’s definition)

This inclines a more general description of the term *model*.
Furthermore, much criticism on Gilbert’s definition was aimed on the term “system”. It was suggested that *system* was replaced with *reality*. Gobert and Buckley (2000) say about this the following: ‘We choose the word ‘system’ because models as representations sometimes add complexity, structure, and a level of explanation that is not inherent in the phenomena itself being described’. This problem was also addressed by one of the interviewed experts, who stated to have a problem with the term “reality”. Instead it was called “reality that is not

reality" and it was suggested to change "reality" to "perception". The point addressed here by Gobert and Buckley (2000) and one of the experts is that what we *perceive* as reality is not necessarily reality and there is not necessarily a one to one correlation between a model and the phenomenon it is based on. It can be argued whether it is needed to replace the word *phenomenon* or *reality* by another term because of this, since we will possibly always rely on a phenomenon in reality as we perceive it. However, this is something that is beyond the scope of this research.

C. Closely Related Terms

The second problem considering the term *model* that was addressed was that of the many closely related terms that exist in respect to the term *model* (Bertels & Nauta, 1969; Duit, 1991; Gilbert et al., 2000). However, this study shows that there is one term in particular that holds a close resemblance to the term *model*: representation. Furthermore it gives an indication of what differences there are between the term *model* and representation, which can be used in the formulation for the term *model* and in thoughtfully using both terms in the future.

D. Learning Objectives

The main objective of this study is to find a set of learning objectives that are fit for teaching lower secondary school students about models and modelling. As said before, there was a chance of compacting too much when creating the scheme of learning objectives and, because of that, of missing desirable learning objectives. Although the scheme turned out to be almost complete, there are also definitely some learning objectives that, based on the commentaries of the experts should also have been part of the scheme:

- *That students learn to work with the different steps in de model cycle*

Learning objective 15 was one of the most desirable learning objectives according to the experts. However, there were also some critical notes. One of these was that – although according to some experts this learning objective *implicitly* implied students going through and completing the modelling cycle – a learning objective *explicitly* addressing the modelling cycle is missing from the scheme.

- *A learning objective that learns students to translate their own mental models to a model*

Another critic on learning objective 15 is that 'students should be able to create models with which they can make clear how they understand the scientific reality': making 'insightful what is going on in their head, as a kind of modelling':
When looking at Figure 1 – describing the relationship between phenomena, mental models and expressed models (Buckley & Boulter, 2000) –, this learning objective can be placed close to "mental model" (in this case it is close to the mental model of the student), where all the other learning objectives can be placed close to "expressed model".
This is interesting, because on one hand, the student learns a skill, and on the other hand, it is a meaningful learning and teaching strategy: The student learns to organize and display his/her thoughts on a particular topic in such a way, that others can see the student's thoughts on the concept. Besides, because the student makes his/her own mental model explicit, the teacher can build on this information. A student rarely comes into the classroom without any knowledge on the concepts that will be taught (Duit & Treagust, 2003; Harrison & Treagust). With knowledge about students' mental models, the teacher can guide the students in *enriching* and *revising* the student's mental model with a specific concept (Vosniadou, 1994).

- *Learning objectives incorporating how models are used in design*

It was righteously pointed out that there is a difference between *descriptive* and *normative* models: ‘some models just try to represent the current reality and […] other models […] give an idea of how it is going to be’. The last kind of models is represented in the applied sciences (which includes e.g. technology), but not covered by the learning objectives in the scheme. This means that the scheme with learning objectives – as it is now – is insufficient to use for all subject described in the *Kennisbasis*. This means that either it has to be made explicit which learning objectives are also meant for models in designing, or that the learning objectives have to be described for this context separately.

E. Features

In a search for coherency between the different subjects, the experts were asked about the eight general features of scientific models (Valk, Driel & Vos, 2007), in the hope of being able to incorporate these features for the different subjects. Although many of the experts agreed with the features in respect to research (although some pointed out that some of the features might not be actual features, something that will not be further discussed here), it can be concluded that they do not think that lower secondary school students should know all these features.

The experts expressed that the first three features were most desirable for students to ‘know’. According to Valk, Driel and Vos (2007), ‘the first two features describe the nature and functions of a model’. The third feature refers ‘to the criteria a model must fulfil in science’. This corresponds with earlier discussed findings that show the importance of the nature of models, the functions models have in science and the notion that models are always made with a certain purpose.

Further comments

It has to be noted that in this research, no distinction was made between the different educational levels. However, it is important that this distinction will be made in the future none the less. However, to be able to say more about this, it is important to talk with people who have more knowledge about and experience with the different groups.

Furthermore, some notes can be made considering putting an emphasis in education on the nature of science and modelling. Vos and Valk (2000) point out that they have some reservations regarding learning students to do research by using models:

> *‘vwo[2] is not intended as vocational training for researchers. Researchers are trained at the University, and in practice often only after the actual University study, namely in the doctoral research. The academic promotion, not the vwo exam, is the aptitude test that a researcher has to go through. Maybe it is therefore not needed for a vwo-student to learn to do research by using models.’*

The same thing can be said for the other educational levels. It is important to be aware of this when interpreting this research and writing learning objectives based on this research. Although there are – besides training students to become researchers, enough other reasons of

[2] One of the four levels in the Dutch secondary educational system.

learning students about the research practice, it is important to keep some kind of balance between science activities and other activities in education.

Although there is some truth in this, it is important to have a decent amount of scientific practice in secondary education. As research shows, students now have little knowledge about the nature of models and the application of models in science (Gobert et al., 2011; Carey & Smith, 1993; Driel & Verloop, 1999). And, since several studies have shown that the understanding of models is related to the science learning of students (Gobert et al., 2011; Gobert & Pallant, 2004; Schwartz & White, 2005), it is important that students know what models are and how they are used in science.
However, knowledge about models and the skill to model should definitely be used and also practiced in other contexts too. Especially in vmbo and havo[3], it is essential to work with models in authentic professional practices, for example: testing prototypes and creating a scheme of a production process.
In all these contexts, students use and develop multiple of these 21st century skills. Models can be used in solving problems and in communication, to base their argumentation on, and to stimulate critical thinking, creativity and analysing skills.

Implications and future research

This study is the first step in the development of learning objectives for models and modelling in lower secondary education that fit the current educational philosophy. Models are a very important part of science and therefore it was a logical step to start with interviewing researchers about their view on models and modelling in education. The final set of learning objectives must be coherent and translated into strategies and teaching methods with which teachers can work on a cross curricular way.
Before that, it is important to research what the teachers of the different subjects think is important that the students know about models and can do with models. In respect to this, it is also important to investigate what distinctions have to be made between the different educational levels. This can be investigated through interviewing individual teachers from the different subjects, but it can also be very insightful to organize group sessions. This makes it possible to find out what the common interests are of the different departments and what ideas they have for a coherent curriculum. In addition, it is important to investigate which contexts (in education, research and professional practice) are suitable for teaching students about models in a joint strategy. Furthermore it is important to see how the learning objectives can be translated into practice, how it can be measured whether students accomplish the learning objectives and how the effectiveness of the learning strategies can be assessed.

[3] Vmbo and havo are two levels in the Dutch secondary educational system that are less theoretical and more practice orientated then vwo (vmbo being most practical)

Advies

Om dit onderzoek te kunnen gebruiken voor de ontwikkeling van leerdoelen, zou ik een advies willen geven, gebaseerd op de kennis die is opgedaan tijdens het onderzoek dat in deze scriptie is beschreven. Allereerst wil ik adviseren over het gebruik van terminologie in wetenschaps educatie instituten. Daarnaast zal ik een voorstel doen voor een set van leerdoelen.

Terminologie

Model is een dubbelzinnige term die wordt gebruikt met meerdere betekenissen in zowel de wetenschap als in het alledaagse taalgebruik. Tot op deze dag is er niet één definitie die wordt gebruikt om (wetenschappelijke) modellen te beschrijven op gebied van wetenschapseducatie. Ik raad aan om binnen de wetenschappelijke en educatieve instituten te praten over de betekenis van modellen en een besluit te nemen over welke definitie in de toekomst zal worden gebruikt. Dit kan bijvoorbeeld Gilberts definitie zijn. Ik moedig aan om ten minste de volgende eigenschappen als onderdeel van deze definitie te beschouwen:

- het is een representatie van iets (een gebeurtenis, idee, object of proces);
- het heeft een bepaald doel;
- het heeft bepaalde functies;
- het speelt een rol in een bepaalde context.

Omdat de termen *model* en *representatie* zeer nauw verwant zijn en tot verwarring kunnen leiden, adviseer ik om ook de betekenis van de term *representatie* te bespreken en te beslissen over de verschillen tussen de termen *model* en *representatie*. Bijvoorbeeld; een representatie is het model zonder het doel, de functie en de context waarin het functioneert.

Leerdoelen

Gebaseerd op alles wat ik tijdens dit onderzoek heb geleerd, raad ik aan om de volgende zaken te benadrukken bij het beschrijven van leerdoelen voor het leren over en met modellen in het lager middelbaar onderwijs:

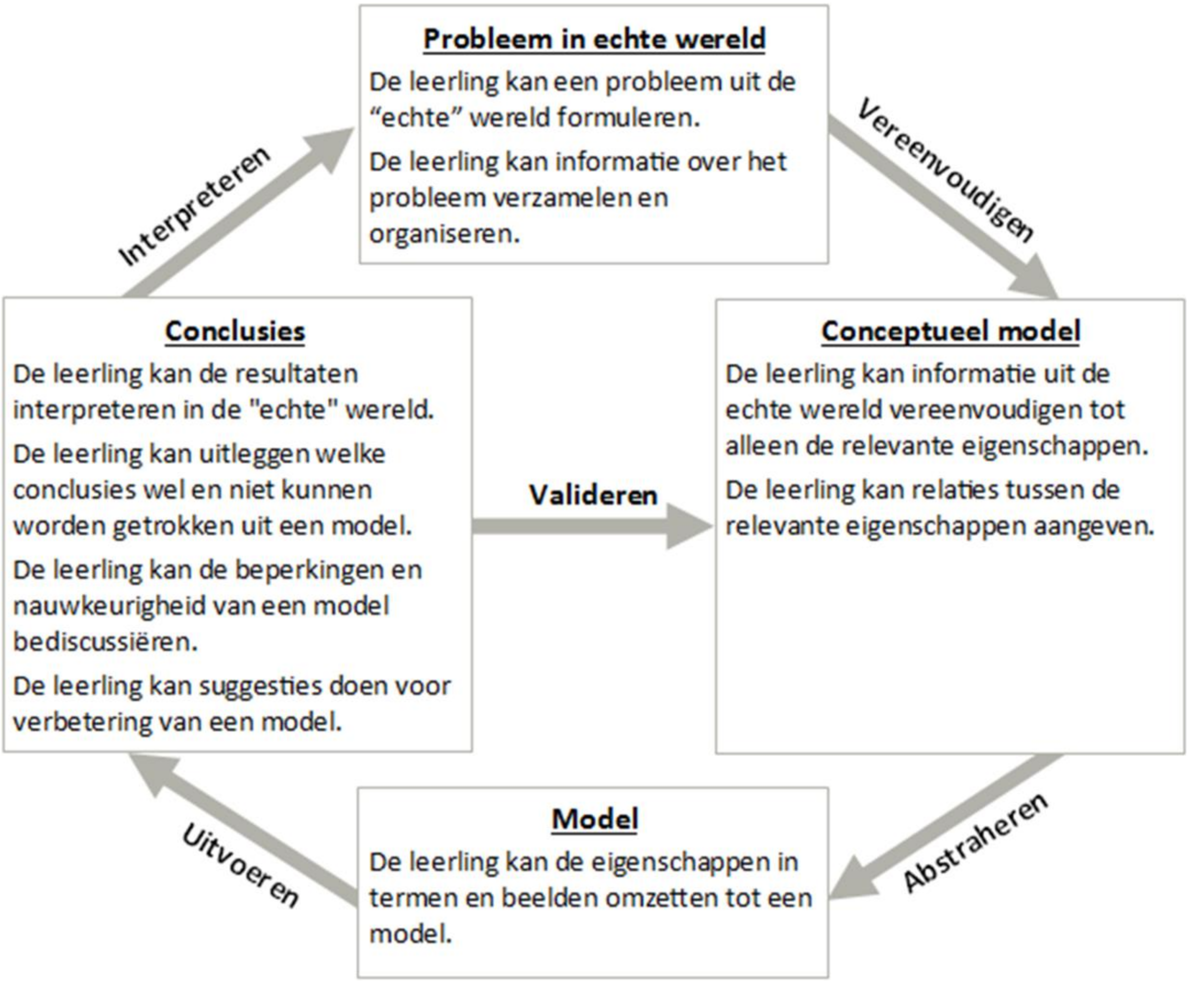
1. dat leerlingen leren werken met de verschillende functies van modellen in plaats van deze functies alleen te leren benoemen, dus: 1) modellen expliciet als een instrument van uitleg en 2) modellen expliciet als instrument voor het doen van voorspellingen.
2. dat leerlingen leren werken met de verschillende stappen van de modelleer- danwel ontwerpcyclus.
3. dat leerlingen leren over de specifieke kenmerken van wetenschappelijke modellen en de aard van de wetenschap die erachter zit.

In navolging hierop, doe ik een voorstel voor een set leerdoelen voor het leren over en met modellen in het lager voortgezet onderwijs:

Modellen gebruiken:
De leerling kan aangeboden modellen gebruiken
- om zich kennis eigen te maken
- voor visualisatie, uitleg en het doen van voorspellingen

Aard van modellen:
De leerling kan beoordelen
- waarin een model overeenkomt en verschilt met de werkelijkheid
- waarin verschillende modellen van hetzelfde verschijnsel overeenkomen en verschillen
- welk(e) model(len) geschikt zijn om te gebruiken in een specifieke situatie

Modellen maken:
De leerling kan een eenvoudig model maken
- om zijn/haar eigen denken zichtbaar te maken
- gebaseerd op en consistent met bestaande kennis
- om een ontwerp te testen
- aan de hand van de modelleercyclus:



Bovenstaande figuur is geïnspireerd door Drijvers (2012) en Maki en Thompson (2010).

Het is belangrijk om met leraren van alle “inbegrepen” vakken (apart en samen) te spreken over welke modellen moeten worden opgenomen in het curriculum en hoe deze algemene leerdoelen kunnen vertaald naar meer concrete leerdoelen zodat ze kunnen worden toegepast in de onderwijspraktijk.
Bij het vertalen van deze leerdoelen naar de onderwijspraktijk, adviseer ik dat er rekening wordt gehouden met het *niveau* van de modellen (deze moeten niet te eenvoudig of te complex zijn) en dat de lesstof in een variëteit aan *contexten* wordt aangeboden (en niet beperkt wordt tot onderzoek).

Verdere aanbevelingen

Om de kennis die de leerlingen hebben over modellen optimaal te verbeteren, adviseer ik verder het volgende:

- Herziening van inhoud leerboeken: Toon modellen niet alleen als feit. Laat in plaats daarvan meer zien van het wetenschappelijke proces dat erachter zit en van de aard van de modellen. Besteed meer aandacht aan aspecten van de aard van de wetenschap. Voeg activiteiten, vragen en reflecterende begeleiding toe, gericht op de verschillende stappen in de modelcyclus en de aard van de wetenschap en gericht op het stimuleren van leerlingen om modellen te maken of te testen.
- Verbetering van de kennis van de leraren: Train leraren. Het is belangrijk dat leraren hun kennis over alle aspecten van de aard van modellen verbeteren, maar ook dat ze meer kennis krijgen over de andere aspecten: om de leerlingen optimaal te kunnen onderwijzen over modellen, om modellen te kunnen gebruiken in het onderwijs en om leerling modellen (geüitte mentale modellen) te kunnen begrijpen.

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Appendix 1 – Topic List

Interview Modellen en Onderwijs

1. Introductie

Voorstellen

- Wie ben ik?
- Wat kom ik doen?
- Deelnemer bedanken voor medewerking

Uitleg doel interview

- Onderzoek naar wenselijke en haalbare leerdoelen voor het gebruik van modellen in de onderbouw van het voortgezet onderwijs.
- Mijn doel is om tot een aantal leerdoelen te komen voor de natuurwetenschaps- en technologie-vakken. Hierdoor zal het eenvoudiger zijn om bijpassende leerstrategieën te ontwikkelen en te selecteren.
- Hoewel er veel literatuur is over onderwijs en modellen worden hier vaak heel verschillende zaken mee aangeduid en de terminologie is verwarrend. Een van de doelen van dit onderzoek is om hier een duidelijk overzicht van te maken.
- Als onderdeel van mijn onderzoek wil ik graag een aantal mensen interviewen met kennis over educatief onderzoek, een achtergrond in één van de beoogde vakken en kennis over modellen binnen dat vakgebied.
- Vanuit deze interviews zal ik een overzicht maken. Mogelijk zal ik U ook in een tweede ronde benaderen om uw mening te geven over dit overzicht.

Verloop interview

- Duurt ongeveer een uur.
- Ik ben geïnteresseerd in uw meningen en ervaringen.
- Tussendoor mogen vragen worden gesteld.
- Het interview zal worden opgenomen en anoniem worden verwerkt.

Toestemming audio-opname

- Mag ik van u dit gesprek opnemen?
- Zo ja; apparatuur aanzetten.
- Ik vraag het nogmaals voor de opname: vindt u het goed als ik dit gesprek opneem?

2. Achtergrond expert

Voordat we met het interview beginnen, zou ik graag een aantal dingen over u willen weten:

a. Kunt u aangeven op wat voor manieren u tijdens uw carrière in aanraking bent geweest met wetenschappelijke literatuur over modellen?
b. Kunt u een publicatie noemen die hierin toonaangevend is?

3. Terminologie

Definitie

c. Wat is het eerste dat bij u opkomt als u het woord ‘model’ hoort?
d. Hoe zou u het begrip ‘model’ in uw eigen woorden definiëren/beschrijven?
e. Waar dienen modellen volgens u voor?
f. In welke omstandigheden worden modellen volgens u gebruikt?

presentatie van een modeldefinitie Gilbert

g. Bent u het eens met deze definitie?
h. Mist u iets aan deze definitie?

Synoniemen

presentatie van een aantal woorden gerelateerd aan de term model

i. Zou u kunnen aangeven welke van deze termen qua betekenis het dichtst bij de betekenis van de term model liggen?
j. In welke kenmerken komen de betekenissen van deze termen overeen en in welke verschillen ze van het begrip model? → ALLE TERMEN AFGAAN
k. Zijn er andere termen die volgens u ook in dit lijstje zouden moeten staan?

4. Leerdoelen

Zoals gezegd, is het doel van dit onderzoek om uiteindelijk met een aantal leerdoelen te komen betreffende modellen in de onderbouw van het voortgezet onderwijs. Hierbij is het belangrijk om te kijken naar de wenselijkheid en de haalbaarheid van de leerdoelen.

l. Welke leerdoelen betreffende modellen zijn volgens u wenselijk voor de onderbouw van het voortgezet onderwijs?
   1) Waarom zijn deze leerdoelen van belang?

presentatie van een aantal leerdoelen

Hier is een overzicht van de leerdoelen die in de literatuur te vinden zijn. Deze leerdoelen zijn niet specifiek (alleen) voor de onderbouw van het voortgezet onderwijs.

m. Waar kunt u uw leerdoelen terugvinden in dit schema?
n. Bent u het eens met dit schema?
   1) onderschrijft u de andere leerdoelen die in dit schema staan?
      I. Mist u leerdoelen?
   2) Vindt u het een duidelijk schema om leerdoelen in te delen?
o. Zijn er andere leerdoelen die u na het zien van het schema belangrijk vindt voor de onderbouw?
p. Welke leerdoelen uit dit schema zijn volgens u haalbaar voor de onderbouw van het voortgezet onderwijs?
   1) Waarom kiest u voor deze leerdoelen?

presentatie van de kenmerken (bij leerdoelen 5 en 9)

q. Bent u het eens met deze kenmerken van modellen in onderwijs én onderzoek?
   1) Mist u kenmerken? Welke?
r. Welke van deze kenmerken zouden leerlingen aan het einde van de onderbouw moeten (kunnen) kennen volgens u? → voor onderwijs? Voor onderzoek?
   1) Waarom kiest u voor deze kenmerken?

Ik ben bij het einde van het interview aangekomen. Hebt u nog vragen?
Wie zou u nog meer aanraden om “hierover” te interviewen?

Bedanken

Kenmerken van modellen
(bij Leerdoel 5 en 9)

1. Er is een strikt onderscheid tussen model en het object van onderzoek.
2. Een model dient als:
   a. Een hulpmiddel bij onderzoek aan het betreffende object. Het wordt als zodanig gebruikt omdat het object zelf niet toegankelijk is voor rechtstreeks onderzoek.
   b. Een representatie van de wetenschappelijke kennis over het object van onderzoek, te gebruiken bij het maken van beslissingen over kwesties (in technologie, geneeskunde, maatschappij, ...) en bij het leren.
3. a. Een model vertoont een aantal overeenkomsten met het object van onderzoek.
   b. Zodoende kan een uitspraak over een zeker model worden 'vertaald' in een hypothese met betrekking tot dat object. Toetsing van zo'n hypothese (indien mogelijk) leidt tot nieuwe kennis over het object van onderzoek.
4. Een model verschilt in bepaalde opzichten van het object van onderzoek. De verschillen maken het model aantrekkelijker voor onderzoek dan het object van onderzoek.
5. Aangezien het hebben van overeenkomsten (3.a) en verschillend zijn (4.) leiden tot tegenstrijdige eisen op het model, zal een model altijd het resultaat zijn van een compromis tussen deze eisen.
6. De bouw van een model vereist creativiteit om zijn doel optimaal te kunnen dienen.
7. Verschillende consensus modellen kunnen naast elkaar bestaan met betrekking tot hetzelfde object van onderzoek. Afhankelijk van de gevraagde precisie, kan één model de beste zijn, in ieder geval voor het moment.
8. In de loop van een onderzoek kan een model een ontwikkeling doormaken die een iteratief karakter heeft.

Closely related terms

Analogie
Beeld/afbeelding
Metafoor/beeldspraak
Paradigma
Patroon
Prototype
Representatie
Schema

Definitie

‘A model is a simplified representation of a system, which concentrates attention on specific aspects of the system. Moreover, models enable aspects of the system, i.e., objects, events, or ideas which are either complex, or on a different scale to that which is normally perceived, or abstract to be rendered either visible or more readily visible.’

LEREN OVER MODELLEN

LEREN MET MODELLEN

De leerling kan

1. een model gebruiken om kennis te verwerven
2. van een in de les gebruikt model aangeven waarin dit overeenkomt en verschilt met de werkelijkheid
3. meerdere modellen van hetzelfde verschijnsel kunnen vergelijken in welk aspect van de werkelijkheid deze laten zien

IN HET ONDERWIJS

De leerling kan

4. aangeven wat de functies zijn van modellen in het onderwijs
5. kenmerken van een onderwijsmodel noemen
6. uitleggen welke conclusies wel en niet mogen worden getrokken naar aanleiding van het model in het onderwijs
7. beoordelen welk(e) model(len) in een bepaalde leersituatie geschikt zijn

IN HET ONDERZOEK (NOS)

De leerling kan

8. aangeven wat de functies zijn van modellen in het onderzoek en de beroepspraktijk
9. kenmerken van een onderzoek-model noemen
10. de beperkingen en nauwkeurigheid van een model bediscussiëren
11. beoordelen welk(e) model(len) geschikt zijn om een bepaald verschijnsel te onderzoeken

LEREN MODELLEREN

De leerling kan

12. suggesties doen voor hoe het model verbeterd kan worden
13. (delen van) een model veranderen voor een bepaald doel
14. een model ontwikkelen door componenten van meer dan één model te combineren
15. eenvoudige modellen maken (door middel van aangeboden modelleersoftware)