Fostering students' understanding of biological models using Modelling-based Learning

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Abstract

Understanding of scientific concepts, observations, methodology and processes are known as integral parts of scientific literacy. Model reasoning and modelling contribute to this. Since models in science education are mostly presented as ready-made models, students do not experience the complete cycle of modelling. This obstructs students in their modelling competences and understanding of models. Modelling-based Learning seems an effective strategy in engaging students into scientific modelling, and in supporting students' understanding of scientific models. This study focused on models in biology education, more specific, concept-process models. These models are known as the most challenging and abstract type of models for students. The aim of this study was to determine whether Modelling-based Learning (MbL) fosters students' understanding of models of biological processes. To do so, a first cycle of an educational design-based research has been conducted. A MbL-activity as well as semi-structured interviews were conducted in two classes of upper secondary school pre-university (VWO) level students (15/16 years old) at a Dutch secondary school in Nieuwegein. Results show that MbL did foster students' understanding of biological models on all model aspects. This indicates that MbL fosters students' understanding to at least level one or higher on all model aspects. Furthermore, interview results indicate that at least six students reached the highest level of understanding on at least one aspect. However, the effect of MbL on students' understanding of biological models has to be determined by comparing the results with an initial level of understanding.

Keywords: models, modelling, model understanding, Modelling-based Learning, Scientific Literacy

Introduction

The view on science education is shifting from a fundamental perspective towards a more social and cultural perspective in which students are expected to acquire social and individual skills that support them to play a responsible role within society (Holbrook & Rannikmae, 2007). These elements are known as key elements in enhancing students' scientific literacy. Scientific literacy involves student's ability to identify scientific concepts in order to understand phenomena in the natural world, scientific processes in order to collect and assess evidence for several processes and scientific situations in order to translate scientific skills into practice (OECD, 2007; Sadler & Zeidler, 2009; Holbrook & Rannikmae, 2007; Holbrook & Rannikmae, 2009).

Scientific models and modelling in science education can be seen as integral parts of scientific literacy (Louca & Zacharia, 2012; Schwarz et al, 2009). In science and science education, models play an important role in connecting scientific theory to society, since models help to visualize and communicate scientific findings (Gilbert, 2004; Louca & Zacharia, 2012). A scientific model has several applications in science education, for example as a simplification of the observed reality. Furthermore, it can serve as idealization of a possible reality in which abstractions of theory can be concretized for better understanding of the abstract theory (Gilbert, 2004). Therefore, model reasoning might be useful as a tool for enhancing scientific literacy among secondary school students (Kolstø, 2001). Furthermore, students' understanding of scientific models is considered as important for their understanding of the Nature of Science (Krell, Reinisch & Krüger, 2015). However, in order to effectively use models in the science curriculum to foster scientific literacy, students should be able to obtain and apply skills that support them in understanding scientific models.

In the current study, the focus will be on scientific models in biology education. Scientific models in biology education are mostly used for illustrative or communicative purposes as ready-made models: models that are previously developed by educators and presented to students to explain a specific biological concept (Schwarz et al., 2009). Moreover, teachers' intentions of the type of models they use in science education, often do not match students' interpretation of the different model types (Harrison & Treagust, 2000). This obstructs students in applying their prior knowledge, create and apply their own mental models, and critically reflect on the reliability of the presented model (Louca & Zacharia, 2012). Effective support in developing a sufficient understanding of scientific models in biology should help students to obtain full advantage from the application of models in science education and their understanding of the Nature of Science (Gilbert, 2004). Therefore, strategies to effectively engage students into scientific modelling and to foster students' understanding of scientific models might be able to support this.

Modelling-based Learning (MbL) seems to be an effective strategy in engaging students into scientific modelling, and in supporting students' understanding of scientific models (Louca & Zacharia, 2012). Constructing models helps students to make concrete representations of abstract processes and promote model reasoning. However, scientific modelling is still rarely applied in science education (Windschitl, Thompson & Braaten, 2008). More research on the added value of scientific modelling and how to apply this in science education is needed to see whether scientific modelling supports students' understanding of scientific models.

This study focuses on students' understanding of models of biological processes in biology education. The aim of the study is to determine whether Modelling-based Learning fosters students' understanding of models of biological processes.

Theoretical background

Types of models

Various types of models are used in science education, each with a different goal or demand. Harrison and Treagust (2000) reviewed data generated from several studies concerning models in science education, from which they developed a typology or classification of analogical models. They define analogical models as simplifications of phenomena or scientific systems to make these more understandable for students and to facilitate scientific communication. Ten types have been identified, four of these types are frequently being used in biology education. The first type is the scale model. This model reflects the external structure of an original (i.e. organ, cell or human body). The second type is known as simulations. Many dynamic processes are described in textbooks, in order to give motion to a dynamic process simulations can be used. These types of models help students to visualise dynamic processes as they occur in the original (i.e. blood circulation or muscle contraction). The third type of models are the theoretical models. These models are constructed by scientists based on a combination of theoretical findings. Theoretical models can make theoretical situations or structures more concrete to students (e.g. DNA structure). The fourth type of model used in biology education are the concept process models. In these models concepts are displayed as a network of interconnected elements that are all part of the process that is being depicted.

The focus of the current study will be on the concept-process models, since these models are known to have an abstract nature due to the mostly non-observable phenomena and multiple ways of approaching (Harrison and Treagust, 2000). Besides, students are required to apply and connect several elements into a concept-process model. This makes concept-process models challenging for students. Harrison and Treagust (2000) state that in order to be able to understand this type of models students are required to be competent modellers. Furthermore, they highlight the need for broadening experience with reasoning and using multiple variants of models throughout students' science courses. In biology education, several concepts can be explained in a concept-process model, for example spermatogenesis, mitosis, thermoregulation or photosynthesis (Chi et al, 1994). Concept-process models are used to teach immaterial processes to students, and to make abstract processes more concrete to students (Harrison & Treagust, 2000).

Modelling-based Learning

Modelling encourages students to reason with and evaluate scientific phenomena that supports students' scientific literacy (Louca & Zacharia, 2012). Sins et al. (2005) found that students that use a modelling based approach are indeed able to enhance their understanding of the different parts and their relation within a model. However, they also concluded that modelling can be experienced as difficult by students in connecting their constructed models to their prior knowledge, to understand the basics of dynamic modelling, or to fit their constructed models into scientific standards. Therefore, students should be provided with appropriate support in scientific modelling to guide them through their model reasoning process.

Modelling-based Learning (MbL) is an approach that focuses on students' construction of models of physical phenomena. This approach enables students to be actively involved in the process of scientific modelling. MbL helps students to activate prior knowledge, collect and combine observations into a model, critically reflect on their work, and revise the model. Louca and Zacharia (2012, (p. 473)) define MbL as an 'approach for teaching and learning in science whereby learning takes place via students' construction of models as representations of physical phenomena that include representations of physical objects and their characteristics, physical entities and physical processes involved in the physical phenomena'.

In the MbL-approach it is important that students incorporate their own observations or experiences in their constructed models, and that they are enabled to test, critically review, and revise it. Louca and Zacharia (2012) reviewed a variety of studies that developed different steps involved in the MbL-approach. They combined the findings of these studies into four steps of scientifically constructing a model:

(1) Students make their own systemic observations or collect their own experiences of the studied phenomenon.
(2) Students construct a model based on the findings in step 1.
(3) Students evaluate the constructed model based on the following criteria: usefulness, predictive power, or explanatory adequacy.
(4) Students revise their model, and try to apply it to new situations.

While constructing an activity based on MbL, these four steps should be taken into account in order to support students' understanding of scientific modelling. Since students require prior experience with models and modelling, the task should connect to the prior knowledge of students. Adequate support and concrete steps will guide students through the modelling process, and help them in their understanding of scientific models (Krell et al., 2015; Louca & Zacharia, 2012; Sins et al., 2005). The four-step-model of MbL supports students in their model reasoning and guide them through the cycle of modelling. Furthermore, MbL seems promising in supporting students' understanding of models of biological processes.

Assessing students' understanding of biological models

Models exist in various types and complexity levels. Since students find it difficult to understand models, it is important to closely look at students' model reasoning in biology (Sins et al., 2005; Harrison & Treagust, 2000; Grünkorn et al., 2014). Upmeier zu Belzen and Krüger (2010) generated a theoretical framework based on data from previous studies on the levels of complexity and the different aspects of models. They identified five different aspects of models:

(1) Nature of models: this aspect focuses on the entities and nature as well as on the kinds of models that include the different views on the nature of science;
(2) Multiple models: this aspect refers to comparing multiple models of the same scientific concept or process being presented;
(3) Purpose of the model: this aspect includes the different views on the purpose a model can serve in biology education;
(4) Testing models: this aspect describes the assessment of credibility and validity of the model;
(5) Changing models: this aspect refers to changing the constructed model based on the outcome of the aspect Testing models.

The above described model aspects are a combination of different empirical studies, combined into a theoretical framework for assessing students' understanding of biological models. Grünkorn et al. (2014) empirically evaluated the theoretical framework generated by Upmeier zu Belzen and Krüger (2010). Based on this empirical evidence they created a revised version of the theoretical framework.

The revised framework for assessing students' understanding of biological models has been corrected in the different levels of complexity for the aspects Multiple models, Testing models and Changing models. Grünkorn et al (2014) added an initial level to these aspects, since some students were not able to reach level one on these aspects. The revised framework consists of the before mentioned five aspects: Nature, Purpose, Multiple, Testing and Changing models. For each aspect a level ranging from initial to level three is assigned. The framework can be used to assess students' level of understanding of biological models. In the current study this framework will be used as an assessment tool for evaluating students' level of understanding of models of biological processes.

Aim and Research Question

The aim of this study is to design a Modelling-based Learning activity that fosters students' level of understanding of models of biological processes. This aim leads to the following research question: To what extent can Modelling-based Learning foster students' understanding of models of biological processes?

Methods

In this study, a first design of a Modelling-based Learning (MbL) activity was developed and tested in an early phase of design-based research study. This was based on the method of educational design based research (Van den Akker et al, 2006; Plomp & Nieveen, 2007). MbL and the five different aspects of students' understanding of models were combined into a design of a MbL activity and interview which was tested in a classroom setting.

Participants

A total of 54 (40 female; 14 males) upper secondary school pre-university (VWO) level students (15/16 years old) from a Dutch secondary school in Nieuwegein participated in this study, and completed the MbL-activity. The MbL-activity was conducted in two classes of 26 and 28 students taught by the same teacher.

Research design

To gain more insight into the effect of MbL on students' understanding of models of biological processes, an MbL activity was developed (see appendix 1). This activity was designed based on the guidelines of the four different steps in MbL reviewed by Louca and Zacharia (2012) (see page 5). The steps of MbL guide students through the process of modelling. The support for choices in the design of the modelling task and the expected learning results are shown in the hypothetical learning trajectory (HLT, see table 2).

MbL activity

The design was based on the process of thermoregulation, as this is an example of an abstract process with interconnected elements in a feedback loop. Furthermore, this concept was not discussed in class, minimizing the influence of existing models of the same process and students' preconceptions about the subject.

Based on the guidelines of MbL, the activity was divided in the four phases: exploration, construction, evaluation and revision phase (HLT, see table 2). In each phase different aspects of understanding were fostered. For example, during the exploration phase an activity with collecting observations and experiences was included in the form of an informative text about thermoregulation. Information from this text provided the elements for constructing their model. This example contributes to the aspect Nature of models. Students are triggered to describe the extent to which the model of thermoregulation resembles the original process in the human body (Grünkorn et al, 2014). The other aspects of understanding of biological models, purpose of, multiple, testing and changing models, were also included in the design (HLT, see table 2). Students worked individually on the MbL activity. The MbL activity was pilot tested with two students.

Interviews

Individual semi-structured interviews with 12 students were conducted after the MbL-activity in order to assess students' understanding of models of biological processes. Participants were randomly selected from the group of 54 students that completed the MbL-activity. Two extra selection criteria for the interviews were to have an equal distribution of boys and girls and the same amount of students from both classes was used.

During the following biology lesson, students were invited to answer several interview questions about their understanding of models of biological processes. Prior to the interview students were told to answer the questions elaborately, and there are no right or wrong answers. The questions were based on the five aspects of the understanding of biological models (see appendix 3) and pilot tested with two students. For each aspect at least one interview question was formulated. Students' answers were audio-taped during the interviews and transcribed verbatim.

Pilot phase

The design has been pilot tested in two rounds (table 1). Results indicated that students answered intuitively, instead of using the information from their constructed model. Also, most answers were too concise. Based on the pilot tests, additional references to students' constructed model were added, in order to put more emphasis on their model rather than prior knowledge or experience. Furthermore, small adjustments were made to stimulate students to explain their answers more elaborately.

After the students finished their modelling task, a semi-structured interview pilot was conducted. The interview questions seemed to fit the expected outcome, since all aspects were scored. Yet the question: 'what is the goal of your model?' required some extra explanation in order to be answered in the correct way. Examples of different goals were added to the question.

The second pilot was performed with two new representative students, indicating the adjusted MbL-activity worked out well. Students answered questions with the information from their constructed model, rather than on their own preconceptions. Also, students' answers were more elaborate and well explained. The design of the modelling task used in the second pilot has been used during the intervention.

Table 1. Participants (N) during the different phases of designing

Phase	N students	Interview
Pilot 1	2	2
Pilot 2	2	2
Intervention	54	12

Table 2. Hypothesized Learning Trajectory (HLT) of the designed Modelling-based Learning activity, including added column of MbL step.

MbL step	Task	What students do	Hypothesized learning result
Collection of observations and experiences	Collect important elements of thermoregulation from a given situation, and indicate the relationships between the elements. (**assignment 1+2**)	- Students gather thermoregulation related elements/concepts from the text, and write them down to make a list of important concepts. - Students think about and write down the role of each element in the process of thermoregulation.	Students learn to see a process as a system of cooperating parts that all together work as a control circuit. (**Nature Level I**)
Construction of the model	Draw a model of thermoregulation based on the "observations" in the previous task. (**assignment 3**)	- Students combine the elements selected from the text into a concept-process model of thermoregulation in the human body	Students learn to see the essential elements of the process, relations between the different elements that combine the process into a working system (**Purpose Level II**)
Evaluation of the model	Test the model on a provided new situation about raising body temperature (fever). (**assignment 4+5**)	- students try to explain the phenomenon in a different situation using their previously drawn model. - Students identify problems/incomplete parts of the model.	- Students will gain insight into the evaluation process of models. They will learn to see that models cannot completely cover every situation. (**No code**)

			- Students will learn to describe necessary adjustments for congruity between the model and the original. (**Testing Level II**)
Revision of the model	Add new/extra elements to the model and/or change relations between elements to improve the quality of the model. (**assignment 6**)	- students look back to the model and try to identify missing elements/relations in their model. - Students add new elements or change relations between elements in their model.	- Students will learn to describe necessary adjustments for congruity between the model and the original. (**Changing level I**) - Students learn to make alterations based on errors and missing elements in their model (**Changing Level I**)
Evaluation of the model	Test the model again on the same provided situation about raising body temperature as in assignment 4 (fever). (**assignment 7**)	- Students try to explain the phenomenon again using their revised model.	- Students will gain insight into the evaluation process of models. They will learn to see that models cannot completely cover every situation. (**No code**) - Students will learn to see that testing models is necessary to check whether their adjustments for congruity between the model and the original improved their model. (**No code**)

	Comparing models with classmates. Identify similarities in and differences between the models. Determine the usability of both models. (**assignment 8+9+10**)	Students compare their model with their neighbors' model. Look for similarities and differences.	- Students see the possibilities of focusing on different aspects of models, different views and different ways of focusing on the original (**Multiple Level II**)
Revision of the model	Changing models based on new research outcomes. The process of making and adjusting models to improve the model. (**assignment 11, 12, 13**)	Students formulate a hypothesis based on new not yet explained observations. Students try to give a hypothetical explanation the new observations using their own model.	- Students learn to test hypothetical situation with their model. Based on this they will come up with suggestions for improvement about the hypothesis and model (**Testing Level III**) - Students learn to change their model based on new findings from experiments. (**Changing Level III**) - Students learn to see that models can be used as examination tool to examine hypothesis about the original (**Purpose Level III**)

Data analysis

Data has been collected in two ways: written answers to the MbL activity and verbal answers to the semi-structured interviews.

Written answers to the questions of the intervention task were coded, based on the five aspects of the understanding of biological models using the framework for assessing students' understanding of biological models composed by Grünkorn et al (2014) (appendix 3). For each written answer, aspect levels of understanding (ranging from lowest (initial/1) to highest (3)) were assigned. Each answer was provided with a code from which the corresponding aspect and level of that specific aspect could be deduced

Pronunciations of students were assigned to the corresponding aspect and level of understanding of biological models based on the theoretical framework for assessing students' understanding of biological models by Grünkorn et al (2014).

Codes of the intervention (20%) as well as the interviews (10%) were assessed by a second independent rater, to determine the interrater reliability. The Cohen's Kappa for the MbL activity was 0.63 and for the interviews Cohen's Kappa was 0.89.

Results

Modelling-based Learning activity

Analysis of students‘ written answers in the Mbl activity resulted in data on the understanding of models of biological processes among the participants (Figure 1). The results are shown as a percentage of students, categorized over each of the five aspects of understanding of biological models. On the aspect Nature of models almost all students (96%) were scored on the lowest level. For both Purpose of models and Multiple models the percentage of students were more evenly distributed over level one and two, where no students managed to reach level three. The same applies to changing of models. However, for this aspect more students were scored on initial level and level one. Most students in the aspect testing models are scored as level one, meanwhile this is the only aspect for which one student managed to reach level three.

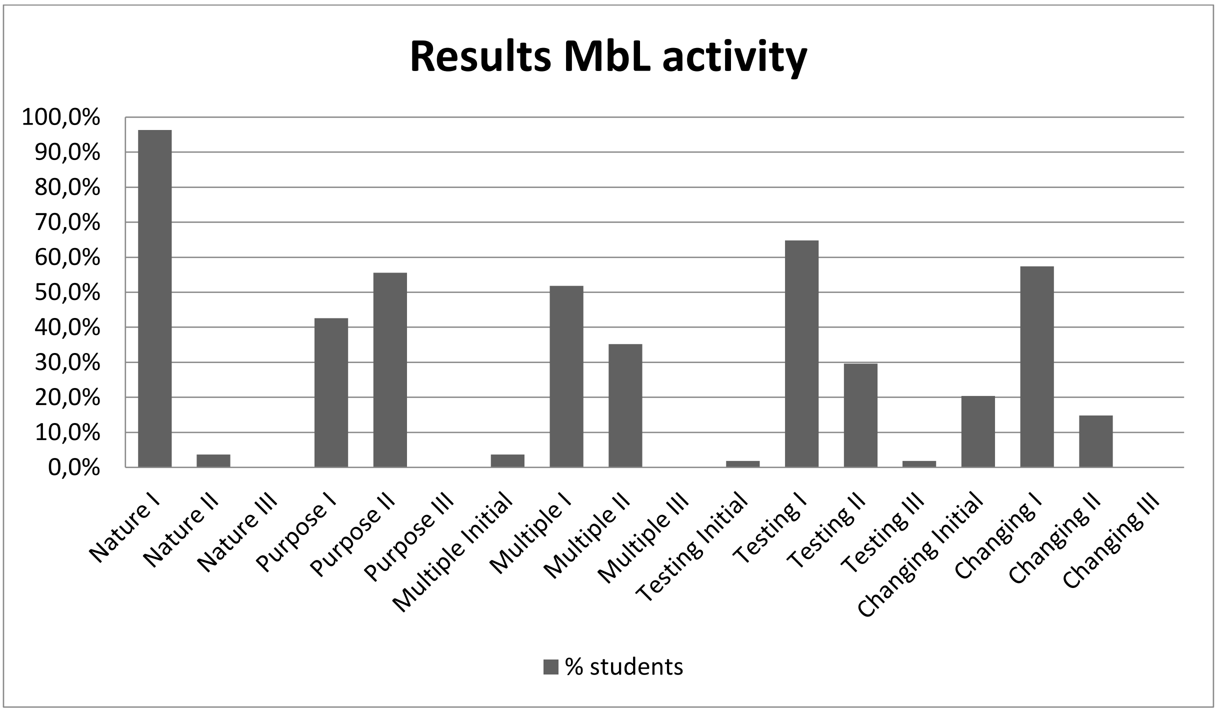

Figure 1. Percentage of students from the participants (N=54) of the MbL activity categorized on level of understanding of models of biological processes. The X-axis shows the five aspects (Nature, Purpose, Multiple, Testing, Changing) of understanding ranging from lowest to highest level (I, II, III). The Y-axis shows the percentage of students in the different categories.

Semi-structured interviews

Figure 2 shows the percentage of students categorized over each of the five aspects and aspect level. On the aspect of Nature of models most students (82%) reached level two, while no students reached the highest level for this aspect. In the following fragment from the interview with student 5 (S5), an example of a statement on level two of the aspect Nature of models is shown. In this example the student mentions that parts of the model resemble the original, and other parts where the student is unsure about that.

R: Can you say something about the extent to which this model reflects reality?

S5: Well I think it does. As in terms of that impulses are sent, because that is also mentioned in the text here […] if the effector only affected this, because in the end, there was also the brown fat which are all things I do not know about yet. So maybe there are more things that I do not know.

For Purpose of models the distribution of students is more equally, with a slightly higher percentage of students reaching level two. In the following fragment of the interview with student 2 (S2), an example of a statement on level two of the aspect Purpose of models is shown. In this example the student explains the purpose of the model as identifying and explaining relations between the different elements. In the final statement the student mentioned the relation between the elements in the constructed model.

R: Can you explain exactly what you mean by those symbols, those words and those arrows?

S2: […] for example that they direct, so to speak, here it means that at this temperature sense it gives a kind of signal to the control centre, and this also means that it then gives an impulse, which is indicated with the arrow.

For the aspects Multiple and Testing models, students were almost equally distributed over all levels, with a slightly higher amount of students in Multiple level two. On these aspects students were able to reach the highest level of understanding. One example of an answer on the highest level of understanding for the aspect Testing models is stated below. In this example student 4 (S4) explains that a model can be tested by thinking of a new research design with comparable conditions as in the original experiments to test whether the hypothetical situation in the constructed model is correct or not.

R: How can be determined whether your model is correct?

S4: By doing experiments […] put a test person in a test room, ask this person to do some exercise and measure the impulses in the test persons' body […] use a thermometer and test when the temperature rises, and after how long the sweat glands start producing sweat.

On the aspect Changing models, more students (75%) were scored on level one relative to level two (25%). No students reached the highest level for this aspect.

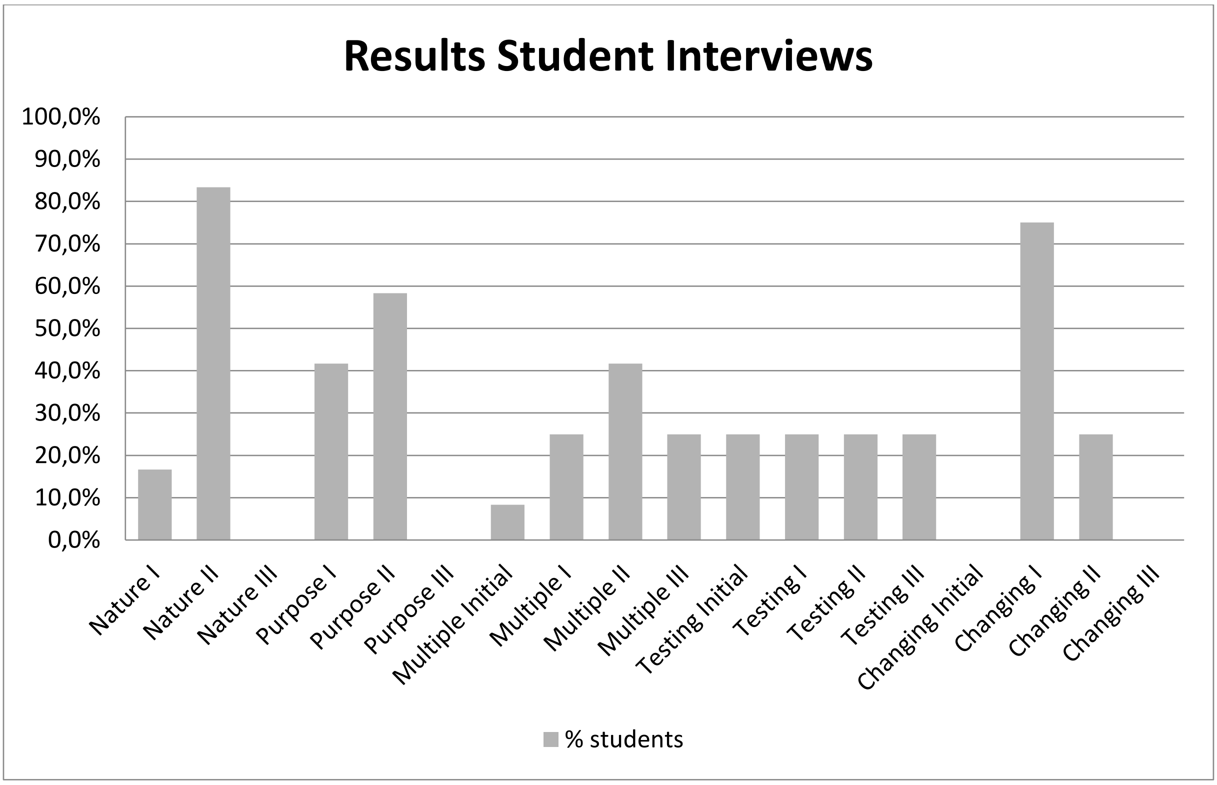

Figure 2. Percentage of students from the experimental group (N=12) interviewed subsequent to the MbL activity categorized on level of understanding of models of biological processes. The X-axis shows the aspects of understanding ranging from lowest to highest level. The Y-axis shows the percentage of student's in the different categories.

A comparison of interview with MbL activity

Results from the written answers of the MbL activity were one-to-one compared with the results from the interviews. Information of corresponding aspect levels per phase is shown in table 3. On the aspect Nature of models students in general reached level two in the interviews, whereas the same students scored a level one for the same aspect on the MbL activity. While looking at the differences of Multiple models and Testing models it became clear that students reached higher levels in the interview. Where no level three scores were noticed in the written answers of the MbL activity for these aspects, there are multiple students that were able to reach level three during the interviews. Minor differences were observed in the aspects Changing models and Purpose of models. One student (S1) managed to reach level three on Changing models during the interviews relative to level one in the MbL activity.

Table 3. Comparison between intervention and interview results per student. First column represents the number of the corresponding students. Each letter is the first letter of one of the aspects of understanding biological models. N: Nature of models; P: Purpose of models; M: Multiple models; T: Testing models; C: Changing models. Numbers represent the level of an aspect, from initial (0) to the highest level (3).

Student (N=12)	*MbL activity*					*Interview*				
	N	P	M	T	C	N	P	M	T	C
S1	2	2	1	1	1	2	2	1	0	3
S2	1	2	1	1	0	2	2	1	0	1
S3	1	2	1	2	1	2	2	2	1	1
S4	1	1	1	1	1	2	1	2	3	1
S5	1	2	1	1	1	2	2	2	2	1
S6	1	1	2	1	2	2	2	2	2	1
S7	1	2	2	1	1	2	1	3	3	1
S8	1	2	1	2	0	2	1	3	3	1
S9	1	2	2	1	1	2	1	1	0	1
S10	1	2	1	2	1	1	2	2	3	2
S11	1	1	2	1	2	2	2	3	1	2
S12	1	2	1	2	1	2	2	0	1	1

Conclusion and discussion

The term 'scientific literacy' refers to students' ability to identify scientific concepts, processes and situations in order to understand phenomena in the natural world and translate scientific skills into practice (OECD, 2007; Sadler & Zeidler, 2009; Holbrook & Rannikmae, 2007; Holbrook & Rannikmae, 2009). Louca & Zacharia (2012) mention that Scientific models are integral parts for developing scientific literacy among secondary school students. However, in order to effectively use scientific models in science education to support scientific literacy, students should be competent modellers and have sufficient understanding of scientific models (Grünkorn et al. 2014). Louca & Zacharia argue that Modelling-based Learning (MbL) is considered as an approach that helps students to achieve better conceptual understanding and develop procedural and reasoning skills concerning models. Furthermore, it enables students to discuss and reflect upon their understanding of scientific models. This study focused on fostering students' understanding of models of biological processes.

Results were collected from students' written answers on the MbL activity and answers to semi-structured interview questions. The results of the MbL activity indicate that students reached level one and two on at least one aspect. Whereas, interview results showed that six out of twelve students reached level three on at least one aspect of understanding. A comparison between the MbL activity and interview results indicate that the level of understanding differed in a number of respects. In general, students achieved higher levels on several different aspects during the interview than on the MbL activity (see table 3).

The aim of this study was to determine whether Modelling-based Learning fosters students' understanding of models of biological processes. A first cycle of educational design based research has been conducted to develop a design according to the four phases of MbL: data collection, model construction, evaluation and revision. Based on this aim the following research question was formulated: To what extent can Modelling-based Learning foster students' understanding of models of biological processes?

In the current study a design of a MbL activity was developed aiming to trigger students' model reasoning in all five aspects of biological models (i.e. nature, purpose, multiple, changing and testing). As shown in figure 1, all five aspects of understanding of biological models were triggered as can be extracted from students' written answers to the questions of the MbL activity. However, almost none of the students reached the highest level of understanding except from one student on the aspect Testing models. Furthermore, on the aspect Nature of models, almost all students reached level one. This indicates that the designed questions did not seem to trigger reasoning on higher levels within the framework. For most questions this was as expected, as can be viewed in the hypothetical learning trajectory (See HLT, table 2). Although, questions 12 and 13 were designed to foster students on the higher levels of understanding on several aspects (Changing, Multiple, Purpose), results indicate that students were not able to reach a higher level of understanding than level two. However, interview results indicate that students were able to reason on the highest level of understanding for some of these aspects (Table 3, S4, S7, S8, S10, S11). This indicates that these questions should be revised or extra sub questions should be added in order to foster higher levels of students' model reasoning in the MbL activity.

Thus, to what extent can Modelling-based Learning foster students' understanding of models of biological processes? The results of the MbL activity show that all aspects of understanding were triggered, and that on at least one or more aspects of understanding students reached level two. For the aspect Purpose of models more than half of the students reached a level two of understanding. This indicates that the design fosters students understanding of biological models on all aspects, however students were not able to reach the highest level on all aspects due to the design of questions. However, interview results show that several students were able to reach level three on at least one aspect of understanding.

Several differences could be observed while comparing results from the written answers of the intervention task with the individual interview answers (table 3). Results show that students are able to reach a higher level of understanding of models of biological processes while being interviewed than when performing on the MbL activity. This indicates that the interview questions may have triggered students to think and respond in higher levels about the five aspects of understanding of biological models, compared to the results on the written answers to the questions of the MbL activity. In an ideal situation, students are expected to reach a certain level of understanding on the MbL activity that resembles the level in the interviews, since the questions of the MbL activity and the interview questions were both designed following the framework for assessing students' understanding of biological models by Grünkorn et al (2014). Students that reached a level two on the aspect Testing models, should also reach level two on the same aspect in the interview. In this study several students differed in two or more levels on certain aspects of understanding in the interview relative to the MbL activity. A new phase in this educational design based research should focus on reducing the difference in results, to end with an efficient tool to assess students' understanding of biological models based on written answers.

The difference in these results could be explained by the quality of students' answers. More detailed and more elaborate answers can be coded more easily than short less detailed answers. When comparing the written answers of the MbL activity with the transcribed answers of the interviews, differences in the length and detail of the answers can be noticed. On the MbL activity students were more likely to answer the questions concisely than during the interview. This could be explained by the way in which the interviews were conducted. The semi-structured interview questions allowed to ask sub-questions to the students for extra explanation of their answers. This resulted in elaborate and well explained answers, which enabled students to reach higher levels during the interviews than on the MbL activity.

Another explanation of the differences could be that fostering students on all five aspects of understanding of models of biological processes might not be feasible in a single lesson MbL activity. The MbL activity was designed to foster students on all five aspects. However, it was not possible to design the questions on all five aspects on the highest level of understanding. This would have end up in an activity that could not be completed in one lesson of 60 minutes. This indicates that students were not able to reason on the highest level of understanding on some aspects the MbL activity regardless if they were able to or not. In the design, practical decisions were made to foster students on at least three of the five aspects on the highest level, because this resulted in a 60 minutes activity. The interview results were designed to check whether their level of understanding on the MbL activity corresponds to their actual level of understanding.

Limitations

The results of this study indicate the extent to which MbL can foster students' understanding of models of biological processes. However, the design was only tested in two classes (N=26; N=28) Dutch tenth grade pre-university level students from a secondary school at Nieuwegein taught by the same teacher. Nevertheless, these results could give a general indication of the extent to which MbL fosters students understanding for all students in the Netherlands of similar age and level. Expanding the design over the rest of the students in the Netherlands should give data to conclude to what extent MbL can foster students understanding of models of biological processes for all Dutch pre-university level students.

Moreover, whether fostering of students' understanding is directly related to MbL remains unclear. A general initial level for all Dutch pre-university level students is not determined yet. Therefore, the results cannot be compared with an initial level of understanding. To determine the effect of MbL on students understanding of models of biological processes, students' levels of understanding should be compared with the initial level of Dutch pre-university students. This comparison could answer the question whether the results are caused by MbL, or whether the results are similar to the initial level of understanding of Dutch students.

Recommendations for future research`

This study conducted a first cycle of an educational design based research on MbL and students' understanding of biological models. The first round of testing resulted in promising results, however this also resulted in adjustments in the design. For the next cycle of tests the design could be optimized by making adjustments in the MbL activity. These adjustments should be included to overcome the limitations as mentioned before, and to reduce de difference in results.

Since fostering all aspects in a design of one lesson is not feasible, it would be recommendable to split the MbL activity into five aspect-specific activities of one lessen. This means that separate activities should be designed for each of the five aspects, which enables students as well as the design of lesson materials to go deeper into their reasoning about models of biological processes. Questions and activities fostering different levels of understanding of biological models can be designed following the guidelines of MbL.

As Harrison and Treagust (2000) argued, different types of models are used in science education. However, also within a specific type of models differences can be observed. For example, in concept-process models in biology education, variation in models can be observed. Within these models not only the processes differ, also the abstraction level or organization level can differ. Students' reasoning on different levels of organization in biology is part of systems thinking (Verhoeff et al, 2008; Boersma et al, 2011). This is an important skill in biology and it is also part of the Dutch curriculum for biology education (Stichting Leerplanontwikkeling, 2015). Future research on the extent to which MbL can foster students' understanding of models of biological processes can be conducted with varieties of concept-process models, differing on abstraction level and/or level of organization biology.

Scientific literacy is becoming more important in current science education (OECD, 2007; Sadler & Zeidler, 2009; Holbrook & Rannikmae, 2007; Holbrook & Rannikmae, 2009). Reasoning about models helps students to become more scientific literate, since the emergence of models entails several characteristics belonging to scientific literacy (Louca & Zacharia, 2012). By engaging students in the cycle of modelling, students might gain a better understanding of the complete modelling process and the different aspects of models (Louca & Zacharia, 2012; Grünkorn et al, 2014). Modelling-based Learning is an approach that guides students through the cycle of modelling. In this study, we translated the MbL approach into a design of a MbL activity, aiming to foster multiple students in their understanding of biological models.. However, the effects of MbL on students' model understanding might also be of added value for other courses in science education. Furthermore, it can be applied on different types of models and for different concepts in science education. Therefore, expanding research on MbL over other science courses and use it with different types of models could be interesting for future research. Ultimately, this hopefully results in an approval of MbL in science education contributing to promoting students' scientific literacy.

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Appendices

Appendix 1: MbL activity design lesson materials. Text boxes extracted from the Dutch VWO biology textbook by Jongmans et al (2012).

Maak je eigen model van: Temperatuurregeling

Naam:

Klas:

Leeftijd:

Mensen zijn warmbloedig, dat houdt in dat de lichaamstemperatuur vrijwel altijd rond de 37 graden wordt gehouden. Onderstaande tekst beschrijft de werking van het handhaven van een constante lichaamstemperatuur. Lees eerst onderstaande tekst, en ga vervolgens verder met de bijbehorende opdrachten

Tijdens een dag op het strand wisselt Noahs lichaamstemperatuur. Door het voetballen stijgt zijn temperatuur iets, zwemmen in het koele zeewater laat zijn temperatuur iets dalen en als hij dan in de zon op zijn badlaken ligt, stijgt zijn lichaamstemperatuur weer. Zijn lichaamstemperatuur blijft schommelen rond de 37 graden. Die waarde, de norm, probeert zijn lichaam te handhaven. Daarvoor is een regelkring nodig.

De lichaamstemperatuur van Noah is vastgesteld volgens een bepaalde waarde die wordt aangeduid als de norm. De norm is doorgaans vastgesteld op 37 graden. Een regelkring voorkomt grote afwijkingen in de norm. Regelkringen bestaan uit een receptor (sensor) en een effector (voert opdracht uit) die samen een waarde rond de ingestelde norm proberen te houden. De receptor is in deze regelkring een temperatuurzintuig. Het meet de lichaamstemperatuur. Wijkt de gemeten temperatuur af van de ingestelde norm, dan stuurt het regelcentrum impulsen naar die effectoren die de afwijking kunnen corrigeren (koelen/opwarmen). Zo'n regelcentrum vormt het middelpunt van een regelkring. Het temperatuurcentrum in de hersenstam bijvoorbeeld, 'bewaakt' de norm van 37 graden en zorgt voor passende correcties. Tijdens het voetballen was dat onder andere het activeren van zweetklieren en het verhogen van de doorbloeding van de huid. Dat gaf afkoeling.

Tijdens het voetballen is sprake van negatieve terugkoppeling. Terugkoppeling wil zeggen dat een afwijking van de norm een proces veroorzaakt dat invloed heeft op die afwijking. Bij negatieve terugkoppeling zal dat proces de afwijking tegengaan: het lichaam vangt de verstoring op.

Opdrachten

Model voorbereiden (individueel)

1. Zet de belangrijke onderdelen die betrokken zijn bij de temperatuurregeling onder elkaar in een overzicht in onderstaande ruimte.

2. Nummer de onderdelen, schrijf vervolgens bij elk onderdeel wat de rol van dat specifieke onderdeel is bij de temperatuurregeling in het menselijk lichaam.

Model tekenen (individueel)

3. Teken een model van de temperatuurregeling van het menselijk lichaam aan de hand van opdracht 1 & 2. Zet de verschillende onderdelen in een model dat duidelijk weergeeft hoe de temperatuurregeling in het menselijk lichaam wordt geregeld.

- Maak daarbij eventueel gebruik van een of meer de volgende hulpmiddelen:
  - Tekeningen; Pijlen; Symbolen; Woorden (let op: geen hele teksten);

Model uitproberen (individueel)

In onderstaand kader staat een situatie beschreven waarin de lichaamstemperatuur van Noah verandert. Lees eerst de tekst en ga vervolgens verder met opdracht 4.

Noah voelt zich ‘s avonds beroerd en denkt dat hij ziek is: hij ligt te rillen van de kou en ziet bleek. Verschijnselen die eigenlijk horen bij een te lage temperatuur. En toch is zijn lichaamstemperatuur meer dan 37 graden. Ondanks een extra dekbed heeft hij het koud. Zijn plan om de volgende dag met vrienden te gaan surfen valt in duigen. Hij blijft in bed. Zijn temperatuur blijkt in de loop van de volgende dag nog verder op te lopen. Tegen de avond heeft hij een lichaamstemperatuur van 40.5 graden. Het lijkt erop dat zijn lichaamstemperatuur niet meer verder stijgt, en blijft hangen rond de 40.5 graden.

4. Leg uit hoe het komt dat Noah’s lichaamstemperatuur gedurende de dag blijft stijgen? Maak in je antwoord gebruik van (onderdelen uit) je zelfgetekende model

5. Is je zelfgetekende model volledig genoeg om te verklaren hoe het komt dat Noah’s lichaamstemperatuur gedurende de dag blijft stijgen, of missen er onderdelen?

Ja/nee, want

Model aanvullen (individueel)

6. Vul je model in opdracht 3 aan (met een andere kleur) met de missende onderdelen waar je bij opdracht 5 mogelijk tegenaan bent gelopen. Ga daarna verder met vraag 7.

7. Pak opnieuw je zelfgetekende model erbij. Probeer met je aangevulde model de situatie waarin Noah's lichaamstemperatuur blijft stijgen te nogmaals verklaren, lukt het nu wel? Gebruik in je uitleg onderdelen uit je model.

Model vergelijken (<u>tweetallen</u>)

8. Leg je model naast het model van je buurman/buurvrouw. Vergelijk de modellen met elkaar en noteer tenminste **2** overeenkomsten en **2** verschillen.

9. De docent maakt van 1 van de 2 modellen over temperatuurregeling een figuur op het proefwerk. De docent werkt het model uit op de computer. Adviseer de docent welk model de inhoud van het proces het beste weergeeft. Leg je antwoord uit.

10. Betekent dit dat het andere model niet bruikbaar is voor het uitleggen van temperatuurregeling? Leg je antwoord uit.

Model toepassen (<u>individueel</u>)

The Iceman

Onderzoekers staan voor een raadsel als blijkt dat The Iceman het onmogelijke mogelijk maakt. Jezelf onder laten dompelen in een bak met ijs voor 2 uur, zonder dat je lichaamstemperatuur onder de 37 graden komt, of een marathon lopen boven de poolcirkel, op blote voeten gekleed in slechts een korte broek. Onderzoekers spreken van een medisch wonder.

Onderzoekers denken dat het lichaam van The Iceman anders reageert op kou dan normaalgesproken het geval is. Ondanks de kou, weet hij zonder problemen 2 uur te overleven in een bak met ijs. Onderzoekers proberen te verklaren hoe het lichaam van The Iceman reageert op veranderingen in lichaamstemperatuur. Ze komen met twee mogelijke verklaringen.

(1) Het eerste vermoeden dat onderzoekers uitspreken is dat de spieren in het lichaam van The Iceman onder extreem koude condities (ijs) meer energie verbranden. Door extra te verbranden kan de lichaamstemperatuur constant rond de 37 graden gehouden worden.

(2) Het tweede vermoeden van onderzoekers is dat het lichaam van The Iceman in een staat van winterslaap komt. Dit zou betekenen dat de lichaamstemperatuur van The Iceman daalt, waardoor de stofwisseling vertraagt en hij dus onder een lagere lichaamstemperatuur kan overleven.

11. Stel op basis van <u>één</u> van de vermoedens van de onderzoekers een hypothese op waarmee je kunt verklaren hoe de temperatuurregeling van The Iceman verschilt van de normale temperatuurregeling.

12. Lukt het je, om met behulp van bovenstaande gegevens en je eerder getekende model, te verklaren hoe de temperatuurregeling van The Iceman werkt? Maak in je antwoord gebruik van (belangrijke onderdelen uit) je model.

Ja/nee, want…

Nieuw onderzoek wijst uit dat beide vermoedens van de onderzoekers niet juist bleken te zijn. Onderzoekers hebben namelijk ontdekt dat The Iceman een bovengemiddeld percentage aan bruin vetweefsel in zijn lichaam heeft voor mensen van zijn leeftijd. Bruin vetweefsel bevat veel mitochondriën, en is daardoor in staat om warmte te produceren. Des te meer bruin vetweefsel, des te meer warmte geproduceerd kan worden. Onderzoekers vermoeden nu dat het extra bruine vetweefsel verantwoordelijk is voor het produceren van warmte tijdens perioden van extreme kou.

13. Verwacht je dat het nodig is om het model aan te passen op basis van de nieuwe onderzoeksresultaten die voortkomen uit het onderzoek naar de temperatuurregeling in het lichaam van The Iceman? Indien ja, vul met een derde kleur je model opnieuw aan. Indien nee, leg uit waarom niet.

Ja/nee, want…

Appendix 2: semi-structured interview questions

Interview protocol

Interviews were conducted in an out of classroom setting, one day after completing the MbL activity. Interview questions were semi-structured, allowing the interviewer to ask sub-questions during the interview. Students answered the questions individually. Answers were audio-taped and transcribed verbatim.

1. What is shown in your model? **(Nature / Purpose)**
2. In your model you use (Drawings, Arrows, Symbols, words) What do they mean in your constructed model? **(Purpose)**
3. What does this model not show with regard to the temperature control? In other words, what is missing in the model? **(Nature / purpose)**
4. Can you say something about the extent to which this model reflects reality? **(Nature)**
5. What would be the purpose of your model? **(Purpose)**
6. Can the model also be used for another purpose? **(Purpose)**
    I. i.e. Can the model be used elsewhere? for example Companies, researchers, universities, people not just at school.
7. How can you determine whether your model is correct? **(Testing)**
8. There are more models that deal with the same theme. Why is there not only one model on this theme? **(Multiple)**
9. It could be that your model is being modified. What would be a good reason for you to adjust your model and what could be an example of an adjustment? **(Changing)**

Appendix 3: The revised theoretical framework for assessing students' understanding of biological models, extracted from Grünkorn et al (2014, (p.1676)).

Table 11. Revised *framework for students' understandings of models and their use in science* including levels of complexity and their categories

	Complexity			
Aspect	Initial level	Level I	Level II	Level III
Nature of models	—	Model as copy	Parts of the model are a copy	Model as hypothetical representation
		Model with great similarity Model represents a (non-) subjective conception of the original	Model as a possible variant Model as focused representation	
Multiple models	All models are the same Various models of different originals Only one final and correct model	Different model object properties	Focus on different aspects	Different assumptions Different assumptions with prospects of application
Purpose of models	—	Model for showing the facts	Model to identify relationships Model to explain relationships	Model to examine abstract ideas Model to examine concrete ideas
Testing models	No testing of models	Testing of material	Comparison between original and model	Testing hypotheses
		Testing of basic requirements	Comparison and matching of original and model	Testing of hypotheses with research designs
Changing models	No reason for alteration	Alterations to improve the model object	Alterations when model does not match the original	Alterations due to findings from model experiments
	Alteration of how different originals are represented	Alterations when there are errors in the model object	Alterations due to new findings about the original	
		Alterations when basic requirements are not met	Alterations due to changes in the original	