7 STUDENTS' VERSUS SCIENTISTS' CONCEPTIONS OF MODELS AND MODELLING

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Abstract

In science models are important thinking tools, which are used to generate explanations and predications (Justi & Gilbert, 2002). Also in science education the importance of models and modelling is increasing, because there is an obvious focus on scientific literacy and inquiry based learning. However various studies identified that students have a simple understanding of scientific models, which is less elaborated than the scientific conceptions (Grosslight et al., 1991). In an effort to qualify and theorize these two perspectives, we adopted a qualitative approach to study how students and scientists conceptualize models and modelling.

To research the quality of students' conceptions, we collected data on German students' (grade 10 to 13) relevant concepts of models and modelling in semi-structured interviews. Simultaneously, we assembled established scientific conceptions from academic literature. We then employ the approach of educational reconstruction to align the scientific conceptions with students' conceptions of models and modelling aim at developing appropriate intervention guidelines (Kattmann et al., 1997). Our findings suggest that students perceive models as teaching aids for visualization and explanation; models are recognized to serve for visualization and explanation in scientific contexts too. However, unlike students, scientists conceptualize models as mediators or tools for generating new insights.

1. Introduction and research objective

"All insight is insight in models or via models" (Stachowiak, 1973, p. 56). This quote expresses the important role of models in science and science education. Harrison and Treagust (2000) even conclude that without models, science is neither teachable nor learnable.

However, various studies showed that students have a limited perception of models as depicting miniatures of real-life objects instead of instruments of an epistemological process and that their conceptualizations differ from those of scientists (Grosslight et al., 1991; Treagust et al., 2002). One reason could be that in the teaching and learning context, the descriptive aspect of models is predominantly perceived, whereas the models' heuristic function as thinking and working tools is not recognized. Thus, their role in formulating and testing hypotheses or theories does not seem to be sufficiently developed in school contexts.

This potential shortcoming is especially relevant in science subjects, where models are the major learning and teaching tools (Harrison & Treagust, 2000). Biology classes employ abstract and material models that are all based on mental models (Justi & Gilbert, 2002). Thinking in models enables communication and formation of consensus in science. Therefore, models and modelling are essential for the acquisition of flexible, transferable, and applicable knowledge (Clement, 2000; Gilbert & Boulter, 2000).

The sensible utilisation of models functions as a "door-opener" for a higher understanding of the nature of science because it leads to advanced levels of scientific thinking and working (Leisner, 2005). Model competence, that means the knowing about models and modelling and its application by using and building models (Upmeier zu Belzen & Krüger 2010) is therefore a profound part of scientific literacy (Gilbert & Boulter, 2000; Driver et al., 1996).

Based on this theoretical framework, this paper presents a qualitative survey of German students' (age 16 to 20/grade 10-13) relevant concepts of models and modelling and aligns these findings with scientific concepts of models and modelling as conceptualized in epistemological literature (Stachowiak, 1973; Mahr, 2008). Three components are put into relation with each other to create more effective lessons: students' conceptions, the scientific view, and the didactic structuring (Kattmann et al., 1997).

The survey is embedded in a larger research programme, which includes the design and testing of quantitative instruments in order to assess, support, and evaluate model competence and intervention strategies based on the theoretically founded structure of model competence (Upmeier zu Belzen & Krüger, 2010). Our research aims at deriving teaching guidelines.

2. Theoretical background

The theories which are used as a basis for the research design of our study draw from two fields of theories. The first concerns the required concepts for the survey, i.e. models and modelling. The second theory domain comprises relevant learning theories.

2.1 Models and modelling

Mittelstraß (2004) suggests that a model is a concrete depiction (because of reduction on the main focus). This depiction of abstract or confusing things or circumstances is then easier to understand or easier to realise. Models are used to describe and explain other systems (i.e. originals) or to make predictions about them (Hesse, 1970). Stachowiak (1973) defines that a model is a system, which is built as a purposeful and abstract depiction of another system. We refrain at this point, from adopting a definition as we consider it a contribution of this paper to elaborate the meaning of the term model in our empirical study.

The process of modelling as a derivation of a model from an original is described by Clement (1989) and by Justi and Gilbert (2002) as an iterative, cognitive process. In this process, (mental) models are empirically tested, further developed or changed, and then tested again.

The empirical testing can be made directly with the model or via comparison with data acquired from the original. After the model has been tested, its fit for its purpose has been evaluated, and similarities or differences between model and original are examined, further iterations of this process can follow.

2.2 Students conceptions about models and modelling

Relevant studies about students' conceptions of models and modelling were published for example by Grosslight et al. (1991) and Treagust et al. (2002). Teachers' conceptions of these topics were published for example by Justi and Gilbert (2003) and Crawford and Cullin (2005).

Grosslight et al. (1991) interviewed 7th and 11th grade students about different aspects of models and modelling. In the aspect "kinds of models" almost all students mentioned concrete objects as models for concrete objects. Rarely did they refer to models as representations of ideas or abstract concepts. These students perceive the models to look like the "real" object, but different in scale (mainly the 7th graders). When asked for the "purpose of models", students in Grosslight`s et al. (1991) study identified a wide range of purposes such as: communication, learning and understanding, providing references and examples, observation, making things clear and accessible, etc. Regarding the aspect "multiple models" the majority of the students thought that it is useful to have multiple models for showing different views of the same entity. No student mentioned using multiple models to test different hypotheses.

Questions regarding aspects like "designing and creating models" students of the 7th grade felt that the modeller tries to make the model as close as possible to the exact size, shape and proportion of the real thing. The 11th graders more often mentioned the consideration of "major and minor" importance of attributes of a model. When asked for likely reasons for changing a model the 7th graders mentioned mistakes and changes in the reality, whereas the 11th graders mentioned reasons like new findings through research, experimentation, or discovery. However, they do not consider that the model itself can be a profound part of this research. Grosslight et al. (1991) identify three general levels of thinking about models.

Treagust et al. (2002), who examine students` understanding of models in science (*N* = 228) during the age of 13 to 15, present in some points results that are corresponding to Grosslight et al. (1991), but Treagust et al. (2002, p. 366) say: "that many students have a good understanding of the role of scientific models in learning science". The need of multiple models is recognized, and the students show "a good appreciation for the changing nature of scientific models". We now want to assess the student's concepts in another cultural and geographical contexts ten respectively twenty years later.

2.3 Scientists conceptions about models and modelling

There are various epistemological attempts trying to clarify, what constitutes a model (Black, 1962; Hesse, 1970; Stachowiak, 1973; Bailer-Jones, 2002; van der Valk et al., 2007; Mahr, 2008 etc.). But the concept is not straight forward. Schwartz and Lederman (2005) present scientists` views of models. In their open-ended survey-based study 70.7% of the 24 natural scientists see models as explanations or a possibility to organise observations that also included testing predictions. Further 37.5% of the participants mentioned the use of models to simplify a complex process or system or as tool to visualise an abstract concept. Nine of the researchers mentioned models as mathematical representations and a few indicated models as a theoretical framework. The study of Schwartz and Lederman (2005) further suggests that the "conceptions of scientific models and their use in science may differ with context of scientific practice".

We therefore assume in our research that the desirable level of model understanding in a learning context can also differ across contexts. However, we aim to identify these different qualities in order to shed light on the breadth of available conceptions of model understanding, their properties and implications.

Bailer-Jones (2002) interviewed nine scientists on the topic of scientific models. She recognizes that the definitions for models are rather diverse. Bailer-Jones (2002) found that models are recognized as representations for phenomena which belong to reality and that they are perceived as a subject to empirical test. Models are simplified and hence enable focussing on the essence. She further identified three dichotomies in the way models are perceived: (1) capturing the essence versus accuracy, (2) satisfying empirical tests versus not being true and (3) being about reality versus only capturing the essence.

2.4 Model competence

Our conception of model competence is suggested as the reflective use of models, which recognizes the tentative, hypothetical and subjective character of scientific models. It can be the meaningful choice of a model, self-creation of a model and also the communication via models (Upmeier zu Belzen & Krüger, 2010).

Model competence enables a learner to autonomously solve problems using scientific models. During the development of model competence, learners are becoming increasingly aware of the preliminary, hypothetical and subjective character of scientific models and hence realise the nature of science (Lederman, 2004). Upmeier zu Belzen & Krüger (2010) developed a theoretical structure of model competence identifying the five aspects: "nature of models", "multiple models", "purpose of models", "testing models" and "changing models". Each of this subdomains is differentiated into three levels (corresponding with Grosslight et al. (1991), Justi and Gilbert (2003), Crawford and Cullin (2005)) with an increasing understanding of models as tools for scientific inquiry. We want to point out, however, that in the context of this study we do not assume that the theoretical structure of model competence is a model of the development of a student – it can also be used as a (context-sensitive) classification.

2.5 Learning and teaching theories

As we pointed out in our introduction, our research is concerned with scientists' and students' conceptualizations of models (cf. Treagust et al., 2002). We assign an important role in reconciling these views to the teacher. In this context, a study of van Driel and Verloop (2002) found that teaching activities are only poorly addressing the students' views of models and modelling abilities.

This mismatch and our focus on the role of the teacher motivate the theoretical approach of educational reconstruction (Kattmann et al., 1997) as our methodological research framework. It addresses the gap by considering existing students' conceptions and aligning them with established scientific conceptions in order to design a learning environment that effects a conceptual reconstruction (cf. Krüger, 2007).

Educational reconstruction assumes a moderate constructivist epistemology (Gerstenmaier & Mandl, 1995; cf. Riemeier, 2007) where knowledge acquisition is viewed as a constructive process that involves actively generating and testing alternative propositions (Tyson et al., 1997). The knowledge is constructed in an active and self-determined process. Starting point for the constructing process are the actual existing conceptions of the learner. This theoretical background helps to understand the learning processes.

A further theoretical influence is the theory of conceptual change (Strike & Posner, 1992; Duit & Treagust, 2003). It is viewed as an outgrowth of the constructivist epistemology (Tyson et al., 1997). Students have a background of central commitments which organises their learning (like scientists). Conceptual change occurs, when these commitments require modification (Tyson et al., 1997). The students have to acquire new concepts and a new way of seeing the world (Tyson et al., 1997). The conditions of conceptual change are intelligibility, plausibility, fruitfulness and dissatisfaction with existing concepts (Strike & Posner, 1992). An active role is played by social and motivational factors in the learning environment (Strike & Posner, 1992). While we are aware of the recent notion of "conceptual reconstruction" and its emphasis on the self-determined construction by students (cf. Krüger, 2007), we maintain the original term conceptual change in the context of this paper.

This theoretical background helps to understand the conditions for conceptual change and therefore also for learning processes.

2.6 Research questions

Following the three elements of educational reconstruction, we structure our research into the following three research questions:

1. What conceptions of models and modelling do students have?
2. What conceptions of models and modelling do scientists have?
3. Which strategies for interventions could be derived from these two perspectives?

In the research project, we examine the following prepositions**:**

- Students mainly perceive models as instruments for visualization and explanation.
- The use of models in a scientific way, and their heuristic functions are not or only rarely recognized by students. More “scientific” conceptions are only expressed by very few students.
- Scientists perceive models as representations for ideas, which are the basis for testing and developing ideas.
- The conceptions of students and scientists are different, but also share some common properties. Their interdependency provides useful sources for deriving interventions.

The scientific concepts are not intended for a direct and systematic comparison with students’ understanding but serve as a sensitizing device and ideal for our qualitative interpretation that highlights sophisticated levels of using and understanding models.

3. Research design

We assume that it could be promising to foster model competence by considering the individual concepts of the students. As noted this idea is recognized by the theoretical background of educational reconstruction (Kattmann et al., 1997). The three components of this framework are put into relation with each other to create more effective lessons: students’ conceptions, the scientific view, and the didactic structuring (Figure 1). The three parts of the research design relate to each other in an iterative way. That means that the design of the learning environment is developed on the basis of the conceptions of students and scientists, but also influences the analysis of the conceptions. Changing the perspectives between the three domains of the research design enables a better focus on each aspect.

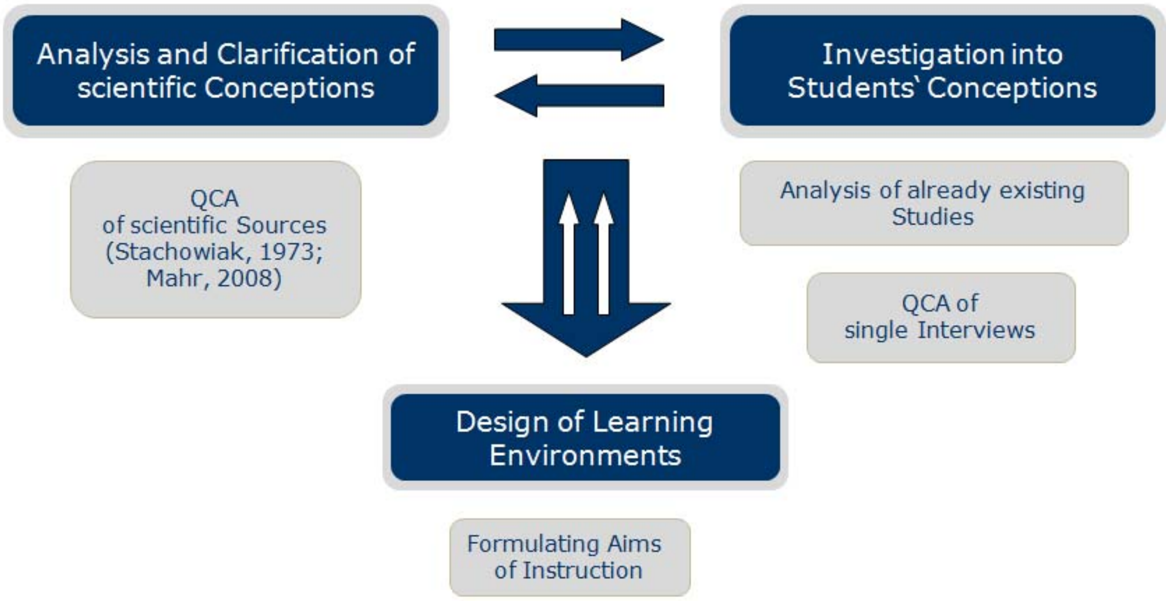

Figure 1. Research Design modified according to Kattmann et al. (1997).

To research the quality of students' conceptions and their influence on using models, we analyse existing findings like the study of Grosslight et al. (1991). Further we collect data in semi-structured individual interviews with students. The main thread of the interviews is based on Grosslight et al. (1991) and is therefore following the sub-domains of the theoretical structure of model competence ("nature of models", "multiple models", "purpose of models", "testing" and "changing"). In the first part of the interviews the students propose own models and express their understanding of them. Then the students get presented some objects, which they should categorize as models or not. Further they should explain why or in which respects something is a model for them or why not. These objects were for example: models related to a biological content, real organisms, preparations of organisms, analogies, pictures of organisms, x-ray prints, microscopic pictures, and models related to chemical or everyday content.

The interviews are audio-recorded, then fully transcribed and copy-edited. The interviews are coded using qualitative content analysis (Mayring, 2003) with the help of MAXQDA. All interviews were coded by a second coder and a discursive validation was carried out until an agreement was achieved. After that for every subdomain (like "nature of models"), the interviewees' statements were sorted, expatiated and structured into single concepts (Gropengießer, 2005).

Parallel to that, we assemble established scientific conceptions from academic literature via the same procedure as described above (QCA with the help of MAXQDA).

For this article we draw on seven single-interviews (age 15 to 20/grade 10-13, male and female students from German school types 'Gymnasium' and 'Realschule') that were selected to create a maximum of diversity and breadth.

4. Results and discussion

We now present our empirical findings with illustrative and representative quotes. For example, Paula responds to an object representing a maple fruit: "*It is a model if you know what it is. It is a model, because you can´t notice more on the parts of the tree than you can see here and that`s why it is a model."* For Paula something can only be a model, if you know what it is, that means if there is an original, where you can refer to. Further a model should be quite close to the original (it`s a model, because you can`t notice more on the original-"nature of models"). She represents the idea of a model as a copy of the original.

For Oliver (class 10) a model: "*is made in a smaller scale than the real thing, which has to be explained with the model. It's used to illustrate and for better explanations*". Further he said: "*They help to explain processes on very small objects, which are invisible for the human eye.* […] *Models are useful for better explanation and better understanding".*

It is a very central aspect for Oliver, that the model has a different scale than the original ("nature of models"). Models are used to visualize and to explain ("purpose of models"). Models make things also accessible ("purpose of models"). The concepts of Oliver are comparable to the findings of Grosslight et al. (1991), in which the main focus of the students` conceptions lies in understanding and explaining.

When Lena (class 11) was interviewed about her definition of a model, she answered: "*A model is an idealised - a replica of something - of a process or an object, an idealised idea of something, which for example exists in the nature. The model helps to represent how it works, without imitating the real world. It isn't the real world*".

She emphasizes that the model is idealised and is not the real world ("nature of models"). In a later phase of the interview she differentiates between models used as teaching aids at school and scientific models. Models for school contexts are used to illustrate and to explain via representing ("purpose of models"). On the other hand she reflects on scientific models: "*Researchers want to go a step further, they want to see further, want to discover more and new things. Whereas for students the known, the discovered is explained with models*". These quotes show how elaborated Lena is thinking about models. On an abstract level she realises the idealised and hypothetical character of models. This finding is corresponding with Treagust et al. (2002). However, once Lena is relating to concrete school contexts, her comprehension of model functions is limited to visualization and explanation: "*Models help to simplify the life, for better comprehension, for faster learning. Also when the original is not accessible, the model can help the teacher to show these things in a smaller scale*". This is corresponding with Grosslight et al. (1991). She seems to not apply her relatively sophisticated and abstract understanding of the nature of models to concrete school contexts, where often only "prepared" models are presented. Treagust et al. (2002) proposed that the mismatch between the abstract realisation of the role of models and the limited application in concrete contexts could be related to a lack of opportunities to use models effectively and applicably in school. Based on our data we hence suggest that special interventions should be targeted in developing from an abstract awareness of the nature of models towards a concrete application in a school context.

If we examine central scientific concepts, models depict something ("purpose of models"), models are reduced (selectively and subjectively- "nature of models") and they are pragmatic (a model for whom, for when and what for – "purpose of models"). It is also a scientific concept that a model is a transporter for a special cargo, i.e. its content. For Mahr (2008) it is very central that nothing is a model per definition, but that something becomes a model by a judgement.

In Table 2 examples of the detected conceptions of both groups are presented across the sub-domains. On the one side we have students, who think that there is no big difference between model and original. We also have students who think that a model is a hypothesis ("nature of models"). But at the end there remains a difference; students believe that there are hypotheses when the object is still not finally clarified. But from their point of view the research process has an end. The scientists know that there is no final state and the findings always remain a possibility. This different conceptualization can also be related to the "purpose of models". Students have rather vague concepts, when they say; models are for experimenting or for getting insights about reality. However, they don't have concrete conceptions of how this can be utilized, for example for finding and testing hypotheses.

Regarding „changing of models", we have students who think that a model can be valid for ever. That means there is no need for changing the model. Also the model will be changed, when the original has changed. But they are not aware that changing a model is an opportunity to get more insight, and that not only the new insight is represented in the changed model. The scientist is aware of the fact that changing the model leads to a change of understanding the original.

The concepts which are different in both groups are interesting, because they help to understand where the students need support and in which direction interventions need to aim. The concepts which we can find in both groups could be a promising starting point for developing intervention guidelines respectively interventions.

Table 2. Examples of selected concepts of students and assessment to what extend these meet the scientists' conceptions. Bold headings reflect the subdomains from the theoretical structure of model competence

Students	Scientists
"Nature of models"	
There is no big difference between model and original.	
A model is idealised.	A model is idealised.
A model is an imagination.	A model is an imagination.
A model is a hypothesis.	A model is a hypothesis.
	A model is a hypothetical possibility.
Everything could be a model.	Something becomes a model by a judgement.
"Multiple models"	
There is only one model for one original.	
There are M.M. because you need an alternative if one is broken.	
There are M.M. for showing different aspects of the original.	There are different model-objects for one model.
There are M.M., because there a different target groups.	
There are M.M. because there are different hypotheses.	
There are M.M. to advance science.	
„Purpose of models"	
Models are for decoration.	
Models are for hobbies.	
Models are for visualization.	Models are for representation. Models have didactic purposes.
Models are for explanation.	
Models are for understanding.	
Models are for orientation.	Models are for orientation.
Models make things accessible.	
With models you can experiment.	
With models you can get new insights about the reality.	With models you can get new insights about the reality.
	Models are mediators.
	Models are for finding and testing hypotheses.
	Models are for scientific theory-building.

"Testing of models"	
	You test the model, regarding his function as a transporter.
You test models via trying if they are working.	
You test models via experimentation.	
You test models via discussion.	
You test a model if it is understandable.	
You test the validity of a model regarding its fit with the original.	You test the validity of a model regarding its fit with the original.
Testing the model brings new insight about the original.	
"Changing of models"	
A model can be valid for ever.	
~~A model can be valid for ever.~~ *	
A model has to be changed if it is not understandable.	
A model has to be changed if it is erroneous.	
A model has to be changed if the original has changed.	
A model has to be changed if there a new insights about the original.	A model has to be changed if there a new insights about the original.
	A change of the model leads to a hypothetical change of the original.

* Negative formulated concepts are formulated positive and crossed out.

5. Outlook

Based on our analysis of the detected concepts one objective for the development of intervention guidelines is to make the students aware of the tentativeness of science via the tentative character of models. There should be an emphasis on the meaning of multiple models for one original as different hypotheses for one original. Also the modelling process itself should be a main part of the inquiry process in science subjects. Such insights should then be applied for constructing learning environments that fostering model competence in a more differentiated way.

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