# Experiences in pedagogy of Design: Research and Design teachers frame of reference about the concept of 'model"

Snjezana de Haan -Topolscak, The Delft, University of Technology
s.dehaan@tudelft.nl
Pauline Vos-de Tombe, University of Technology
s.dehaan@tudelft.nl
Merle Ebskamp, University of Technology
s.dehaan@tudelft.nl

## ABSTRACT

The core of the Dutch Technasium secondary school course Research and Design curriculum (R&D is in Dutch called Onderzoeken en Ontwerpen O&O) is to involve students in real-life design (or research) problems with a problem owner at a company or organisation. Students explore the nature of the design problem, establish a design brief, explore possible solutions and work out one option into a design, a prototype or a product depending on the level of complexity. Students work and learn in teams coached by Technasium teachers. Some secondary school teachers are qualified to teach at Technasium if they obtain a certificate from the Technasium foundation through a number of short training courses. They are originally teachers in various subjects like mathematics, physics, physical exercise, language and so on. The other part of the teachers have a teaching degree in R&D next to a degree in engineering. Thanks to different backgrounds the teachers offer a variety of angles and know-how in different fields of expertise needed during a R&D activities. Such a composition is enriching and STEM supporting at the level of knowledge transfer. It is clear that some R&D teachers have no design pre-knowledge. A pilot survey of R&D students and teachers on the concept of model within design activities unexpectedly showed similar doses of confusion about the concept of model among students and teachers. Therefore when asked to teach a concept of model in design related activities teachers provided a different definition of concept. Often a physically built scale model or prototype is the form of model they recognize in designing. The danger of such an approach is that the students obtain very different, incomplete or incorrect knowledge about the concept of model in relation to design. Therefore the set of values and norms within the group of Technasium teachers is needed, to establish a design related frame of reference.

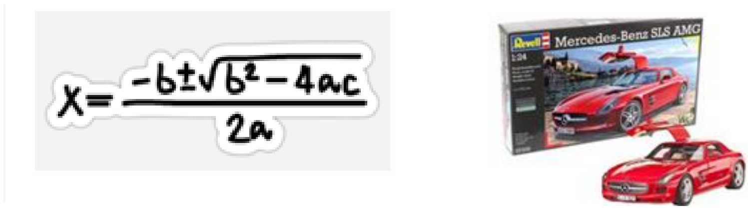
*Keywords; STEM, Subject Research and Design (R&D), Concept, Model, Pedagogy of Design*

## 1. THIS IS A MODEL

The aim of the research was to investigate the conceptual understanding of the term 'model' among R&D teachers with very different subject backgrounds and students. The reason for this was, firstly, that during the execution process of research or design assignment, concept learning is a very important aspect of the R&D subject. The meaning technological concepts have in students' minds directly affect their learning in technology because these concepts form a framework from which to construct other concepts and base actions on (Jones, 1997). Secondly, a survey conducted among students in their final R&D year revealed that the students had various frames of references of the term 'model'. This implies that the development of effective teaching strategies for this topic in the curriculum is necessary.

The survey was designed to explore the diversity of interpretations of the term among the students.. Next to the picture of the model (see figure 1) the same statement was placed "This a Model"; do you agree or disagree?

*Figure 1.*
*Two model  examples; mathematical formula and scaled car*




After informally asking subject teachers of the R&D subject what they understood by the term 'model',  these teachers also did not appear to have the same frame of reference, which may have led to different ideas about what constitutes a model. It appears from various conversations that there may be no agreement on how to use the term 'model' in high school education. Prof. Dr. Van Joolingen (2017) underlines that knowledge about models is essential to teach students to reason critically and to give them insight into the workings of science. Lijnse (2008) endorses this. He states that a lot of research has now been done that shows that both teachers (van Driel 1997) and students (Grosslight et al., 1991; Vollebregt, 1998) have all kinds of problems with models. He cites the statement of Schwarz & White (2005): "there is ample evidence that students may not understand the nature of models or the process of modelling even when they are engaged in creating and revising models". Teachers and students therefore have problems using models. How did that happen?

The term model alone has many definitions, the Cambridge Dictionary (2023) already lists ten. It is difficult to establish unambiguous definitions related to R&D. Furthermore, the teachers have different backgrounds within R&D, in the science subjects, which may entail a different view on the concept of a model. No clear agreement has been found within secondary education on how to define the concept of a model. The Technasium has also not provided a definition of the concept of a model within subject R&D. In secondary education, the term 'model' may be explained by individual subject teachers. However, the question is whether this also happens in interdisciplinary subjects such as R&D. As stated in the abstract, at the moment, all secondary school teachers are qualified to teach at Technasium if they obtain a certificate from the Technasium foundation through a number of short training courses at Technasium Academie, (Technasium Academie 2023). Only difference is the field of teachers' activity known as first or second grade of secondary teaching. This means that the R&D teaching team is usually composed of many different teachers who have competence in different subjects.

Ensuring that teachers share a common understanding of key concepts, such as the 'model, is essential for delivering a consistent, effective, and high-quality education, particularly in interdisciplinary fields like R&D. It enables teachers to provide consistency in the curriculum through effective and coordinated instruction, thereby standardising the learning experience. Students benefit by receiving clear and unambiguous curriculum content and can apply learned concepts in interdisciplinary contexts.

## 2. MODEL WITHIN DESIGN EDUCATION

In order to contour the R&D frame of reference for the concept of 'model', the natural science, mathematics and R&D have been examined in advance for the meaning of the concept of model and classification of types of models. Natural science includes earth science, physics, chemistry, astronomy, and biology, while mathematics is considered one of the four core subjects taught in schools, alongside physics, chemistry, and biology.

In the literature, the term "model" is defined in various ways. Lijnse (2008), Schwarz & White (2005), and Hestenes (1987) all describe a model as a representation of reality with a goal and an alleged area of validity. They differ in their specifics, with Schwarz & White (2005) emphasising representation rules and reasoning structures, and Hestenes (1987) focusing on observable patterns in physical phenomena. In secondary education SLO (2020), a simplified definition is used, describing a model as a schematic representation of reality.

Although there are various definitions of the term model, no unequivocal meaning or definition has been found within the natural sciences, mathematics and R&D for the term “model”. The definition depends on the field of knowledge. A common definition is that a model is 'always a simplification of reality'. Reality is according to Cambridge dictionary (2023) the state of things as they are, rather than as they are imagined to be. Several scientists (Wegner, 2017; Bede, Dennis & Miller, 2016), including Lijnse (2008), argue that a model has a purpose. These goals are very different in nature and can be divided into different main groups. In the absence of a definition, Van Driel (1997, pp. 179-180) has provided a number of characteristics by which a model can be recognized in the natural sciences such as:

- A model is always a model of something, namely of an object of investigation. The object of research can be a system, but also a phenomenon, a process, a 'thing', or something that does not exist (anymore) (such as a dinosaur) or whose existence is uncertain (such as a black hole).

- A model is a tool for research into the object in question. It is used as such because the object itself is not accessible for direct examination.
- A model shows a number of similarities with the object of research. Thus, a statement about a certain model can be 'translated' into a hypothesis regarding that object. Testing such a hypothesis (if possible) leads to new knowledge about the object of research.
- A model differs from the object of research in that reductions are applied when drawing up a model (for example, by deliberately ignoring certain aspects of the object of research in the model), by scaling or in some other way. The pursuit of simplicity plays an important role in the development of models (Ockham's principle). Features 3 and 4 contradict each other.
- A model therefore has a built-in compromise character and the researcher has a certain freedom in choosing a model. The research question plays a role in that choice.
- A model is not derived directly from the object of study, such as a photograph or a measurement result. It contains elements that the object of investigation does not possess. Creativity therefore plays a role in the choice of a model.
- In the course of a study, a model may undergo an iterative development. The object of research is always studied in more detail.

Different classifications are possible to classify types of models within the natural sciences and mathematics. This classification can be made, for example, on the basis of the purpose of a model, a level of abstraction or, for example, on the basis of the subject. In architecture and industrial design, models are often defined and classified on the basis of the design process (Eger, 2010; Knol, 2007; Karssens & Otte 2018). Different types of models are used at different stages of the design process. Usually those models then go from coarse to fine with regard to simplification of reality or level of abstraction. Abstraction is the opposite of reality according to Cambridge dictionary (2023), abstraction is the situation in which the subject is very general and not based on a real situation.

It seems that there is no agreement on the use of the term 'model'. There is no clear and unambiguous definition and classification available. Therefore teachers and students have different ideas about the term 'model' (Lijnse, 2008). This makes it difficult to instruct students about a model's functions and purpose in the design process. Van Joolingen (2017) underlines that knowledge about models is essential to teach students to reason critically and to provide insight into the working of science.

## 3. DEVELOPING FRAME OF REFERENCE

To investigate the conceptual understanding of the term 'model' among R&D teachers with very different subject backgrounds and students, they were asked to describe their own definitions of the term 'model'. This will provide a frame of reference as foundation for clear and unambiguous communication regarding the concept of 'model' within this context. The concept of a frame of reference, as described in the Cambridge dictionary (2023), refers to a set of ideas or facts accepted by a person that explains their behaviour, opinions or decisions. Developing the frame of reference involves creating and expanding upon this knowledge and experience. To achieve this, the research employed two steps.

Firstly, an initial survey was conducted among students in both the first (22 students) and final years (10 students) of secondary school, as well as among 14 R&D teachers. Only science teachers participated in this design research. However, these science teachers are diverse in terms of their qualifications and the subjects (other than R&D) and levels they teach (lower and upper grades). In this research, no specific conclusions are drawn regarding the composition of the respondent group. The purpose of the first survey was to gather insights into their individual definitions of models, their ability to recognize different forms of models, and their perspectives on the potential uses of models. By examining these perspectives, a comprehensive frame of reference for the concept of 'model' can be established. The questionnaire consisted of three parts.

The first part comprised twoo open-ended questions about models: "What is your definition of a model?", "Why do we create models?" These questions aimed to assess the students' previous knowledge and their own understanding of the concept of models.

In the second part of the questionnaire, pictures of various types of models were presented to the students. They were then asked a closed-ended question for each picture: "Is the following considered a model?" This section aimed to assess the students' ability to recognize and identify different forms of models. The pictures included a scaled model car (1:24 scale), a villa maquette, a playmobil horse, a TV schema, a mathematical formula, an organisational chart, a map of the Netherlands with coloured provinces, a cardboard model of a Vespa scooter, a low-cost kids FM radio circuit diagram, and a stuffed toy animal. Different model representations were selected on three levels of abstraction. Lowest level close to the state of things as they are, middle level when objects are close to the state of things as they are with imaginative elements and high level of abstraction when object is no longer connected to state of thing as they are.

The third part of the questionnaire consisted of a multiple-choice question: "Why do we create models?" Students were provided with various answer options, including "To simplify reality," "To highlight important components," "To test prototypes," "To conduct experiments," "To create small-scale examples," "To learn about something," "All of the above," and "Something else." This section aimed to gauge the students' understanding of the purposes behind creating models.

Secondly, a two-question survey was conducted with five teachers who form an R&D team at another school. The second question of the survey was presented in a multiple-choice format, where participants were asked to select characteristics of a model provided by van Driel and Wegner. The purpose of the survey was to assess the similarities between self-verified characteristics and characteristics drawn from the literature, as well as the choice of characteristics from the literature when given. These teachers have diverse qualifications, and they teach various subjects and grade levels (lower and upper grades) in addition to their involvement in R&D.

Van Driel (1997, pp. 179-180) has provided a set of characteristics that can be used to identify a model in the natural sciences. Additionally, Wegner (2017) emphasises that a model always has a purpose. These sources served as the foundation for the multiple-choice question in the survey. The answers from the first question, "What is a model?", were analysed for their alignment with the characteristics described by van Driel and Wegner. This analysis was conducted using the Atlas.ti method.

## 4. RESULTS

The first part of the research survey consisted of two open-ended questions about models to assess the previous knowledge of students and teachers, as well as their understanding of the concept of models. The first question: "What is your definition of a model?" reveals an overlap in goal- and example-oriented definitions in all three groups, highlighting that models serve as simplified representations or descriptions of reality and can be used as examples for something. Furthermore, the definitions given were diverse.

The question of why we create models uncovers different perspectives between students and teachers. While students, both in their first and last year, focus on the purpose of models, such as testing or checking their functionality, and emphasise the benefits and advantages of creating them, such as providing visually appealing representations of how something looks or works, teachers, on the other hand, emphasise the clarifying, communicative, and explanatory role of models, as well as the benefits of visualisation that they offer. Even though a definition from literature also clearly plays a role here, namely that the model always has a purpose, Wegner (2017), it emerges that description of the purpose of the model changes with the role that respondent fulfils within the school. The students opt for testing and presentation and teachers for clarification and explanation.

In the second part of the questionnaire, students were presented with pictures of various types of models. This section aimed to assess the ability of both students and teachers to recognize and identify different forms of models with different levels of abstraction. From the answers, we observed that models which are very close to reality such as scaled car models, villa maquettes, cardboard Vespa were recognized as a model by all groups. In the first year, recognition of models mostly remained at level 1, while in the last year there was an increase in recognition, reaching level 3, see table 1. The interpretations among teachers varied greatly and show in % less confidence in recognition of the model than last year students.

*Table 1 Results overview - Three-step level of abstraction/reality*
*1 = low level of abstraction, very close to reality*
*2 = medium level of abstraction, close to reality thou parts differ from reality*
*3 = high level of abstraction, a model differs from reality*

| **This is a model. Yes, No, I don't know** | **abstraction level** | **22 students first class high school** | **Nine students last year high school 9** | **14 teachers from one school** |
|---|---|---|---|---|
| 1 Scaled car | 1 | **yes 73%**<br>no 27% | **yes 100%** | **yes 93%**<br>no 7% |
| 2 Villa maquette | 1 | **yes 100%** | **yes 100%** | **yes 86%**<br>no 7% ,<br>don't no 7% |
| 3 Playmobil horse | 1 | yes 32%<br>**no 54% ,**<br>don't no 14% | yes 44%<br>**no 56%** | **yes 50%**<br>**no 50%** |
| 4 TV schema | 3 | **yes 50%**<br>no 45% ,<br>don't no 5% | **yes 89%**<br>no 11% | **yes 58%**<br>no 21%<br>don't no 21% |
| 5 Mathematical formula | 3 | yes 13%<br>**no 73% ,**<br>don't no 13% | **yes 56%**<br>no 44% | yes 14%<br>**no 72 %**<br>don't no 14% |
| 6 Organisation schema - organogram | 3 | yes 5%<br>**no 73% ,**<br>don't no 22% | **yes 56%**<br>**no 33% ,**<br>don't no 11% | yes 28%<br>**no 58%**<br>don't no 14% |
| 7 Map of the Netherlands | 2 | yes 33%<br>**no 77% ,** | yes 44%<br>**no 56%** | yes 28%<br>**no 50%**<br>don't no 22% |
| 8 Paper vespa | 1 | **yes 82%**<br>no 9% ,<br>don't no 9% | **yes 78%**<br>no 11% ,<br>don't no 11% | **yes 64%**<br>no 22%<br>don't no 14% |
| 9 FM radio schema | 2 | yes 45%<br>**no 45% ,**<br>**don't no 10%** | **yes 78%**<br>no 11% ,<br>don't no 11% | **yes 64%**<br>no 22%<br>don't no 14% |
| 10 Stuffed animal toy | 2 | yes 18%<br>**no 73% ,**<br>don't no 9% | yes 22%<br>**no 78%** | **yes 50%**<br>no 35%<br>don't no 15% |

The third part of the questionnaire consisted of a multiple-choice question. This section aimed to gauge the students' understanding of the purposes behind creating models. In all three groups, the majority of respondents selected "To highlight important components" as their answer. Additionally, among the students, two other commonly chosen answers were "To simplify reality" and "To test prototypes."

First characteristic to choose was; "A model is always a model of something, namely of an object of investigation" has been chosen unanimously. Therefore the open question answers were again underlined. Second answer chosen by 80 % of teachers was a; "A model is a tool for research into the object in question." Least chosen answer was; "A model differs from the object of research in that reductions are applied when drawing up a model by scaling or in some other way.” This is a very interesting answer because it shows clearly not understanding of changing model level to abstraction.

*Table 2*
*Results of a multiple-choice question*

| Characteristics of model from literature according to van Driel and Wegner | Teachers answers | Teachers answers overlap characteristics of model from literature |
|---|---|---|
| 1 A model is always a model of something, namely an object of investigation. | 5 x yes | 100% |
| 2 A model is a tool for research into the object in question. | 4 x yes | 80% |
| 3 A model differs from the object of research in that reductions are applied when drawing up a model by scaling or in some other way. | 2 x yes | 40% |
| 4 A model shows a number of similarities with the object of research | 3 x yes | 60% |
| 5 A model is not derived directly from the object of study, such as a photograph or a measurement result. It contains elements that the object of investigation does not possess. Creativity therefore plays a role in the choice of a model. | 3 x yes | 60% |
| 6 A model therefore has a built-in compromise character and the researcher has a certain freedom in choosing a model. The research question plays a role in that choice | 3 x yes | 60% |
| 7 In the course of a study, a model may undergo an iterative development. The object of research is always studied in more detail. | 3 x yes | 60% |
| 8 A model should alway has a purpose (for R&D) | 3 x yes | 60% |
| 100% = 40 Similarity with features offered | 65% = 26 Similarity with features offered | |

Coding given answers on the open question “What is a model” showed an understanding by 60% of respondents of a model being a model of something (object). Just one respondent (20%) has an overlap with literature drawn characteristics (Van Driel, 1997; Wegner, 2017) mentioning purpose and reality. Although the answers do not correlate to literature they correlate to each other. The word simplified was named unanimously, representation and scale by 60% of respondents. See table 3. Respondents were all from the same school so this could show an already existing frame of reference.

*Table 3*
*Identifying characteristics drawn from literature coding  answers from respondents*

| Responden t | Answer to the open question “What is a model?” |
|---|---|
| Teacher 1 | A **representation** (3D or 2D) of a **scaled**-down object |
| Teacher 2 | A **representation** of the original object to **scale** |
| Teacher 3 | A **simplified** or **scaled**-down **representation** of a real object or concept. |
| Teacher 4 | **A simplified representation** of reality, with the purpose of providing insight into certain properties (such as proportions, functioning mechanisms, etc.). |
| Teacher 5 | A **simplified representation** of a complex system, where there are multiple possibilities/perspectives to depict this system |

## 5. CONCLUSION

The provided results highlight several interesting points regarding the definition and understanding of models among students and teachers. One significant finding is the overlap in purpose and example-oriented definitions of models, emphasising their role as simplified representations or descriptions of something, often referred to as reality. However, the recognition of models remained predominantly at a lower level of abstraction among young students, with an increase in recognition observed among older students.

Surprisingly, the recognition of models among teachers showed unexpected variation, despite the anticipated increase in abstract level recognition among older students. This suggests a potential gap in  understanding and knowledge among teachers regarding the recognition and abstraction levels of models.

The majority of respondents, across all three groups, identified "To highlight important components" as the main reason for creating models. Additionally, students commonly chose "To simplify reality" and "To test prototypes" as their reasons for making models.

The second survey aimed to compare the characteristics of models found in literature with those named by teachers. It revealed that teachers understood a model to be a representation or model of something, often referred to as reality. The majority of teachers agreed with the statement that "A model is always a model of something, namely of an object of investigation." But at the same time they do not recognise that the model could be different from reality.

Although we can detect similarities between the teachers of the same school on the definition of concept of model, those similarities are a fraction of the available knowledge about the models' goals and definitions. These findings indicate a need for broadening and deepening the set of values, norms, and knowledge among R&D teachers regarding the definition and use of models. Providing teachers with more comprehensive knowledge about the characteristics of models, considering the lack of unanimous choice among the provided definitions, is crucial to establish a common frame of reference and enhance their ability to teach students effectively. Furthermore, the absence of unanimous answers about what a model is and why we make one suggests a potential need for cross-disciplinary courses for teachers in STEM subjects to foster a more cohesive understanding of models across disciplines. The conceptual understanding of the term 'model' among R&D teachers with very different subject backgrounds, within this pilot, is incomplete and ambiguous.

## 6. DISCUSSION

It is clear from this pilot study that R&D teachers lack unambiguous knowledge about the concept of model. Regardless of the number of similarities in answers there are many differences in answers to ignore a lack of knowledge. Comparison between different R&D teams from different schools can provide more clarity about similarities which may be related to school. Abstraction level of the models is not further explored focusing on recognizing purpose and definition of a model.

Nevertheless, focusing on high abstraction level models which differ from reality could be interesting for further research and provide a frame of reference which can connect a curriculum and learning about models in R&D.

This pilot enriched us with knowledge about the narrow frame of reference within R&D teachers regarding model characteristics and purpose. It does not provide an answer why that is so and how we can solve it. It just indicates a problem which might occur in more heterogeneous STEM subjects communities.

## 7. REFERENCES


Bede, D., & Miller, W. (2016). *The engineering design of systems: Models and methods.*Cambridge dictionary (2023, june 23) *Model*, retrieved on June 23, 2023 from |MODEL English meaning - Cambridge Dictionary

Cambridge dictionary (2023, june 23) *Reality* , retrieved on June 23, 2023 from REALITY | English meaning - Cambridge Dictionary Cambridge dictionary (2023, june 23) *Abstraction*, retrieved on June 23, 2023 from ABSTRACTION | English meaning - Cambridge Dictionary

Cambridge dictionary (2023, june 23) *Frame of reference* , retrieved on June 23, 2023 from FRAME OF REFERENCE | English meaning - Cambridge Dictionary

Eger, A., Bonnema, A., Lutters, E., van der Voort, M., (2010), Productontwerpen Boom Uitgevers Amsterdam

Hestenes, D. (1987). American Journal of Physics. *Toward a modelling theory of physics instruction*, 440-454.

Karssen, A. , Otte, B., (2018) Maquettes bedenken maken overtuigen, Noordhoff Uitgevers

Knoll, W., & Hechinger, M. (2007). Architectural models, second edition: Construction technique, J. Ross Publishing. Created from delft on 2022-06-08 18:36:42.

Lijnse, P. (2008). Modellen van/voor leren modelleren. *Tijdschrift voor Didactiek der -wetenschappen, 25*(nr. 1 & 2), 3-24.

Schwarz, C. V., & White, B. Y. (2005). Metamodeling Knowledge: Developing Students' Understanding of Scientific Modeling. *COGNITION AND INSTRUCTION*, 165-205.

SLO. (2020, January 23). *dynamisch modelleren*. Retrieved fromwww.slo.nl:https://www.slo.nl/thema/vakspecifieke-thema/natuur-techniek/modelleren/leerlijn-modelleren/modelleerniveaus/dynamisch-modelleren/

SLO. (2020, January 23). *Modelleren en Modelgebruik*. Retrieved from www.slo.nl:https://www.slo.nl/thema/vakspecifieke-thema/natuur-techniek/modelleren/modelleren/verschillen-gebruik/

Technasium. (2022, April 10). *Onderzoek & Ontwerpen*. Retrieved from Technasium: https://www.technasium.nl/over-technasium/onderzoek-ontwerpen/

van Joolingen, W. (2017, March 29). *Leren van modellen*. Retrieved from Universiteit Utrecht: Studium Generale: https://www.sg.uu.nl/video/2017/03/leren-van-modellen.

Wegner, D. (2017, February 8). *Representaties onder de loep*. Retrieved from Universiteit Utrecht: Studium Generale: https://www.sg.uu.nl/video/2017/02/representaties-onder-de-loep