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Preservice Biology Teachers' Conceptions About the Tentative Nature of Theories and Models in Biology

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Abstract In research on the nature of science, there is a need to investigate the role and status of different scientific knowledge forms. Theories and models are two of the most important knowledge forms within biology and are the focus of this study. During interviews, preservice biology teachers ($N = 10$) were asked about their understanding of theories and models. They were requested to give reasons why they see theories and models as either tentative or certain constructs. Their conceptions were then compared to philosophers' positions (e.g., Popper, Giere). A category system was developed from the qualitative content analysis of the interviews. These categories include 16 conceptions for theories ($n_{\text{tentative}} = 11$; $n_{\text{certain}} = 5$) and 18 conceptions for models ($n_{\text{tentative}} = 10$; $n_{\text{certain}} = 8$). The analysis of the interviews showed that the preservice teachers gave reasons for the tentativeness or certainty of theories and models either due to their understanding of the terms or due to their understanding of the generation or evaluation of theories and models. Therefore, a variety of different terminology, from different sources, should be used in learning-teaching situations. Additionally, an understanding of which processes lead to the generation, evaluation, and refinement or rejection of theories and models should be discussed with preservice teachers. Within philosophy of science, there has been a shift from theories to models. This should be transferred to educational contexts by firstly highlighting the role of models and also their connections to theories.

Keywords Nature of science · Scientific theory · Model · Preservice teachers · Conceptions · Interviews

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Introduction

This article focuses on preservice biology teachers' conceptions of the tentative nature of theories and models in biology, which can be found within the broad research area of "nature of science" (NOS; Sandoval 2005). There is a consensus about the importance of NOS aspects for the development of scientific literacy (Bybee 2002). Hodson (2014) distinguished between four main categories of learning goals, which should be considered by teachers and teacher educators: learning science, doing science, learning to address socio-scientific issues, and learning about science. The latter includes the development of "an understanding of the characteristics of scientific inquiry, the role and status of the knowledge it generates, the social and intellectual circumstances surrounding the origin and development of important scientific theories, [and] defending, scrutinizing and validating scientific claims [...]" (p. 4). These features are included in various standards and reform documents for primary and secondary school education as well as for teacher education (e.g., Germany: KMK 2005, 2014; USA: NGSS Lead States 2013). However, studies concerning the understanding of (preservice) science teachers reveal that they "do not typically possess 'adequate' conceptions of NOS" (Lederman and Lederman 2014, p. 614; see also Lederman 2007).

NOS refers especially to the nature of scientific knowledge, which "is the culmination of scientific inquiry and includes laws, theories and models. Focusing on these structural elements in the context of any single discipline would be necessary to understand the nature of that discipline" (Dagher and Erduran 2014, p. 1204). Following Erduran and Dagher (2014), laws, theories, and models can be called scientific knowledge forms, "that work together to generate and/or validate new knowledge. They are products of the scientific enterprise" (p. 113). Passmore et al. (2014) stated in reference to teachers' experience with models and modeling: "It is clear that teachers (both preservice and inservice) have had very little experience with a view of science as a model-based enterprise and thus may be challenged to enact model-based curricula" (pp. 1197–1198; cf. Windschitl et al. 2008). Studies often reveal a naïve understanding of the role of theories and laws as well as the differences between them (e.g., Liang et al. 2009). Many of the investigations of students' and (preservice) teachers' conceptions about theories have been conducted using paper-pencil instruments, especially with closed item formats, and there are only a few studies explicitly focusing on students' (Dagher et al. 2004) or (preservice) science teachers' understanding of theories. Most empirical work has been done on overall assessments of NOS conceptions, with theories being just one part. As a result, rationales of the respective sample groups and their interpretation in research articles remain superficial. In order to create effective learning opportunities, the consideration of learners' preconceptions is essential (Vosniadou et al. 2008). Therefore, the present study uses a methodological framework named the model of educational reconstruction (MER; Duit et al. 2012; Kattmann et al. 1997). This will allow for a deeper understanding of preservice biology teachers' reasoning about their conceptions about the (tentative) nature of theories and models in biology. Criticism about the strong focus on domain generality within NOS research (e.g., Dagher and Erduran 2014) will be considered by focusing only on biology and not on science in general.

This article aims to contribute to the recently outlined lack of scientific knowledge forms and their relation as a central aspect within school of science (cf. Erduran and Dagher 2014). The focus is on theories and models and their tentative nature as these are seen as central knowledge forms in the domain of biology. Although laws are also seen as important knowledge forms within science (e.g., Erduran and Dagher 2014) and NOS (e.g., Lederman and Lederman 2014), especially within the field of philosophy of biology, there is an ongoing discussion whether there are even any real laws in biology (cf. Reutlinger et al. 2014; Rosenberg 2008). For this reason, there will be no further delineation about laws in this paper, except if there are any connections to models or theories. Since teachers' knowledge about theories and models is essential for adequately supporting students' learning, this article builds on preservice teachers' conceptions in order to use their preconceptions for the formulation of educational guidelines. This can be used to guide teacher training.

A more detailed presentation of the theoretical background, including previously discussed issues within NOS, will now be outlined. Subsequently, the tentative nature of scientific knowledge and different knowledge forms will be presented with a focus on philosophical considerations. Finally, the educational context of this study will be outlined.

Theoretical Background

Nature of Science

What is science? This is the central question in Hoyningen-Huene's (2013) recently published book. The philosopher concluded:

> It turns out that the various sciences and their specialties are so different from one another that it appears as absolutely hopeless to find substantial and universally valid characteristics of them that together might constitute the nature or the essence of science. (p. 209)

In contrast, it appears that at least the general notion of NOS within science education, i.e., aspects of NOS, which are relevant to the teaching and instruction within educational settings, is widely accepted by science education researchers. Thus, "NOS refers to the epistemology and sociology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development" (Lederman et al. 2002, p. 498; cf. Lederman 1992). Many researchers have previously investigated the elaboration of aspects included in NOS. Lederman and Lederman (2014) listed the following features of science as the most important for students to know and work with: scientific knowledge is tentative, subjective, based on empirical grounds, includes imagination and creativity of humans, and is embedded in social and cultural contexts. The authors also emphasize the distinctions between observations and inferences, as well as theories and laws. Finally, it is highlighted that these aspects are intertwined and cannot be seen "as 'mantras' for students to memorize and repeat" (p. 615) but rather have to be included in scientific contexts, which allow for reflections connected to multiple, interdependent aspects (Schwartz et al. 2012).

Since the tentativeness of scientific knowledge plays a crucial role here, this aspect will be discussed further. According to Lederman (2007), scientific knowledge, including theories and laws, changes when new evidence becomes apparent by means of new technology, theoretical reflections, or when old evidence is given new interpretation by means of new theoretical considerations. Furthermore, the changing characteristic of scientific knowledge covers all other NOS aspects and can be seen as one of science's "greatest strengths [because] progress toward legitimate claims and away from erroneous ones would never be possible without skepticism and scrutiny of new and existing claims, along with the possibility of revising or rejecting those that fall short" (Bell 2009, p. 3). Hoyningen-Huene (2013) highlighted that scientists and philosophers, until the late nineteenth century, proposed the existence of the epistemic ideal of absolute certainty of scientific knowledge.

Issues Discussed Within Nature of Science Research

Despite more or less reaching agreement about which aspects should be included in the school science curriculum (e.g., Lederman et al. 2002; McComas and Olson 2002; Osborne et al. 2003), there exists a discussion whether the so-called consensus list should be extended or changed. One aspect concerns a more sophisticated and detailed analysis and inclusion of philosophical views. This would provide a more appropriate aid for teachers and students, as well as potentially reduce misunderstandings (cf. Erduran 2014; Hodson and Wong 2014; Matthews 2012).

Strongly connected with the lack of more detailed philosophical stances, another line of discussion focuses on the lack of several features of science that, it is argued, should be implemented in schools and, therefore, in science teacher education. One of these is the role and importance of models and modeling within scientific contexts (Hodson and Wong 2014; Irzik and Nola 2011; Matthews 2012; Sandoval 2005). Ever since Grosslight et al. (1991) assessed students' and experts' understanding of models and modeling, an increasing effort has been made to study and implement this topic in educational contexts (e.g., Justi and Gilbert 2003; Krell et al. 2015). At the same time, "the study of the particular epistemological aspects of models has been scarce" (Dagher and Erduran 2014, p. 1204).

Some researchers criticize the lack of discipline-specificity of NOS aspects (e.g., Dagher and Erduran 2014; Elby and Hammer 2001; Hodson and Wong 2014; Irzik and Nola 2011, 2014; Samarapungavan et al. 2006; Wong and Hodson 2009). Studies show that students' understanding of NOS aspects differ depending on the scientific discipline, such as biology, chemistry, or physics (e.g., Krell et al. 2015).

Forms of Scientific Knowledge: Theories and Models

Theories and models are seen as "forms of scientific knowledge that work together to generate and/or validate new knowledge. They are products of the scientific enterprise" (Erduran and Dagher 2014, p. 113). A theory is a consistent, testable, and—at least in principle—falsifiable system of statements. Its core functions are to describe, explain, and predict empirical phenomena (Lauth and Sareiter 2005). A definition of a "model" or what constitutes a model is difficult to grasp and differs depending on the literature used. The cognitive agent (i.e., the modeler) determines what a model is and which purpose it has to fulfill (Passmore et al. 2014). Something becomes a model due to purposeful selection and construction processes performed by the modeler (Mahr 2012). What matters is the result of a judgment made by the modeler. Something becomes a model when the modeler sees it as a model *of* something (creation of a model) and *for* something (application of a model; cf. Mahr 2012; Passmore et al. 2014).

In the following, there will be no detailed depiction of the development of theories and models throughout the history of science philosophy but rather a short summary of a contemporary and broadly accepted view of theories and models,[1] which is the semantic or model-based view (Adúriz-Bravo 2012). While proponents of a model-based view had to contend for the recognition of models next to theories in the 1960s, modern philosophers tend

[1] A detailed account of the historical development of models and theories in philosophical discussions can be found in Bailer-Jones (2009).

to ascribe central meaning to models and not theories regarding the description and analyses of scientific phenomena. Hence, a new understanding of models has evolved that automatically revises the understanding of theories (semantic view). Accordingly, models and not theories describe empirical reality (Bailer-Jones 2004), and models are seen as the central unit of scientific theory formation. Giere (1988) described the structure of a theory by means of two elements: "(1) a population of models, and (2) various hypotheses linking those models with systems in the real world" (p. 85). Theories are identified by non-linguistic entities called propositions or statements, which are the assertions of (linguistic) sentences. These propositions can be, for example, (non-linguistic) laws, which are embodied in models. Hence, models have a mediating role between propositions and the real world (phenomena). As Adúriz-Bravo (2012) highlighted, the semantic view is "arguably one of the most developed, well established, and widely accepted schools of the philosophy of science" (p. 1602) and can be implemented in school science. Among other advantages, the meaning of models and an understanding of certain phenomena by using the semantic approach are highlighted.

Educational Framework

With respect to Shulmans' (1986, 1987) work, teachers should possess different kinds of professional knowledge: general pedagogical knowledge, content knowledge, and pedagogical content knowledge (cf. Grossman 1990; van Dijk 2014). An adequate understanding of NOS can be seen as part of teachers' *content knowledge* (CK), whereas the teaching of NOS content to students can be associated with *pedagogical content knowledge* (PCK).[2] For the development of PCK, a solid knowledge of CK and hence, NOS content, is inevitable (Lederman 2007).

To increase preservice teachers' CK about NOS, the model of educational reconstruction (MER) can be used to analyze their conceptions (Duit et al. 2012), which have to be considered in order to create effective learning opportunities (Vosniadou et al. 2008). The model serves as a theoretical and methodological framework to investigate students' and scientists' conceptions about specific topics within science (e.g., Gropengießer 2001: process of seeing) in order to develop and increase the efficiency of learning environments (Duit et al. 2012; Kattmann et al. 1997). Duit et al. (2012) stated that NOS aspects "need to be included in the process of educational reconstruction" (p. 23).

To fulfill the requirements within the MER, three intertwined research tasks (RT) have to be fulfilled: Firstly, the *research on teaching and learning* (RT 1) includes the study of learners' views of scientific conceptions or, in this case, the metastructure of science. Secondly, the *clarification and analysis of science subject matter* (RT 2) is essential. For this, different sources can be used, such as interviews with scientists or primary and secondary literature. Additionally, historical perspectives should be included, since different conceptions about the subject and the associated terms have existed and developed through time (Gropengießer 2001). During this research process, it is important to view subject-specific positions as individual and personal conceptions of the scientists. These positions are compared to learners' perspectives because empirical studies have shown that "surprising and seemingly 'strange' conceptions students own may provide a new view of science content and hence allows another, deeper, understanding of the content clarified" (Duit et al. 2012, p. 22). Concerning

[2] A detailed discussion about the integration of NOS in Shulmans' classification can be found in van Dijk (2014).

NOS, Duit et al. (2012) suggested using philosophy and history of science as reference disciplines. This might also contribute to the aforementioned call by Erduran (2014), Hodson and Wong (2014), and Matthews (2012) to enhance traditional NOS views with more sophisticated views stemming from the philosophy of science. The outcomes of both research tasks have to be presented and discussed simultaneously. Subsequently, these results influence the third research task (RT 3), the *design and evaluation of the teaching and learning environment*. This can be conceptualized in different ways. Typically, interview studies are conducted to provide guidelines that serve as the construction basis for learning environments (Duit et al. 2012).

Aims and Research Questions

The aim of this study was the educational reconstruction (Duit et al. 2012; Kattmann et al. 1997) of the tentative nature of theories and models within biology. The conceptions of both preservice biology teachers and philosophers were assessed and analyzed. The following questions guided the research:

(RQ 1) What conceptions do preservice biology teachers hold about the tentative nature of theories and models in biology?
(RQ 2) What conceptions are presented in relevant philosophical literature about the tentative nature of theories and models?

In order to highlight the characteristics of the understanding of both the preservice biology teachers and the philosophers and to illustrate possible similarities as well as conceivable learning problems, the results of the first two research tasks of the MER were compared and discussed. This was done using a recursive approach, since the results of RT 1 could have influenced the interpretation of the results of RT 2 and vice versa (Gropengießer 2010). Hence, the third research question was proposed:

(RQ 3) What kinds of correspondences become apparent between preservice biology teachers' and philosophers' conceptions?

The overall intent was to formulate educational guidelines on the basis of the comparison.

Methods

Sample Information and Assessment of Conceptions

Preservice Teachers

The sample of the preservice teachers was recruited using selective sampling (cf. Schatzman and Strauss 1973). The following inclusion criteria were set: The participants had to be biology students studying to become teachers. They also had to be interviewed before they accomplished any explicit instruction on NOS aspects. The latter was especially important in order to assess preconceptions that could be built on to formulate instruction guidelines later on.

The sample consisted of ten preservice biology teachers undertaking bachelor-level study, with biology as either their first or their second subject (Table 1). All participants were in their second or third year of a five-year teacher-training qualification at university and had no prior qualifications in a scientific working field. Prior to the interviews, participants had only completed some subject specific courses in biology (e.g., zoology, botany). Furthermore, they had all just started with a lecture and the corresponding seminar concerning specific topics of biology education (module: Introduction to biology education). At the time of interviewing, no explicit NOS curriculum was implemented, and the models and modeling topic had not yet been carried out.

For the assessment of the preservice biology teachers' conceptions (RT 1), semi-structured interviews (between 50 and 90 min) were conducted. "Interviews have a better opportunity to probe [...] context-dependent stances toward knowledge" (Elby and Hammer 2001, p. 561). The interview guideline was developed by both authors. Three test interviews (cf. Niebert and Gropengießer 2014), with preservice biology teachers, were performed by the first author. The participants gave feedback on the clarity of the questions and the proceedings in general. On this basis, the interview guideline was revised. During the interviews, which were performed by the first author, participants were asked about their understanding of theories and models within the domain of biology. The participants were interviewed in two cohorts. The interviews of the first cohort ($n = 5$) did not only aim at the understanding of theories and models but comprised a wider range of topics related to NOS (e.g., scientific methods, nature of scientific knowledge in general, laws in biology). After analyzing and comparing these interviews with science philosophy positions, participants in the second cohort ($n = 5$) were only asked to answer questions about theories and models. The reason was to enable a closer examination of preservice teachers' conceptions. The interviewer could take up previously narrated conceptions of the first cohort in a more detailed way when mentioned by a participant in the second cohort. Both cohorts were asked to specify their general conceptions with references to examples (e.g., theory of evolution). This procedure complies with the requirement of Elby and Hammer (2001) to "contextualize interviews more deeply" (p. 565). The specific context was not given by the interviewer but chosen by the participants. For

Table 1 Sample information

Name	Age (in years)	1. subject of study (semester)	2. subject of study (semester)
First cohort			
Anna (A)	23	Biology (3)	English (3)
Jasmin (J)	21	Biology (3)	History (3)
Leon (L)	22	German (5)	Biology (3)
Marie (M)	22	English (4)	Biology (4)
Pia (P)	19	Biology (ns)	English (ns)
Second cohort			
Clara (C)	23	Biology (3)	Chemistry (3)
Emilia (E)	20	Biology (3)	Chemistry (3)
Finn (F)	26	Biology (3)	History (3)
Hannah (H)	28	German (3)	Biology (3)
Sara (S)	22	Biology (3)	German (3)

Names are fictitious and give no indication of the personal identities of the participants except their gender, *ns* not specified example, the first prompt for cohort 1 was "Please describe what you think about the three concepts 'law,' 'theory,' and 'model' in the context of biology." In cohort 2, we merely asked for descriptions of theories and models. In cases where the interviewees did not give examples by themselves, the interviewer asked, "Please name examples of theories and models within biology you were just thinking of."

During the interviews, the participants were also asked to construct a concept map based on their personal ideas about the subject matter (cf. Novak and Cañas 2006), and to explain their maps (think aloud method; cf. Ericsson and Simon 1993). Prior to the interviews, each interviewee received a standardized, written guideline with instructions of how to construct a concept map. During the interview, different concepts written on cards (both cohorts: theory, model; only first cohort: law, *Wissen* in biology, *Erkenntnis* in biology,[3] experimenting, observing, modeling) were given to the participants. Participants were also encouraged to add their own concepts to their concept maps. The concept-mapping procedure was practiced during the test interviews with the three preservice biology teachers (see above), and the instruction guideline was adjusted to make the process as clear as possible. The concept mapping served primarily as a support for the interviewees to organize and illustrate their conceptions in a detailed way (Novak and Cañas 2006). This also helped the interviewer to address contradictions and inaccuracies expressed by the participants during the interviews.

Philosophers

Within the field of philosophy of science there is a broad range of conceptions about theories and models. Historical views are of particular interest, since it is assumed that common learners' conceptions are also represented in (especially early) science philosophy literature. Analyzing these historical sources is seen to be advantageous for the interpretation of students' conceptions (Gropengießer 2001). Contemporary literature in the philosophy of science also includes parallels to learners' conceptions. This literature mainly serve as current generally accepted views within science philosophy to form a basis for the development of learning arrangements and goals. For the selection of literature, introductory works were used to achieve an overview of prominent (historical) philosophical views (e.g., Bailer-Jones 1999; Wiltsche 2013). In order to keep the analysis of these within reasonable limits, at least one of two criteria had to be met for the selection and analysis of a specific philosophical position (RT 2). First, literature sources chosen (Tables 4 and 5) delineate current, widely accepted philosophical considerations or, second, feature similarities or partial parallels to the interviewees' conceptions. For example, one of the preservice biology teachers used the popular example of Popper's white and black swans to explain her idea of falsificationism. Therefore, some of Popper's (1934/1971) work from "The logic of scientific discovery" was analyzed.

Data Analysis

Preservice Teachers

The analysis of the interviews was performed using qualitative content analysis (Mayring 2000, 2002), which presents an "approach of empirical, methodological controlled analysis of

[3] Interviews were conducted in German. Both *Wissen* and *Erkenntnis* can be translated as "knowledge." Following Vollmer (1975a), *Erkenntnis* includes a process (cognition) and a result (*Wissen*).

texts within their context of communication, following content analytical rules and step by step models [...]" (para. 5).

The recorded interviews of the first cohort were transcribed and edited. Categories were developed using the qualitative data analysis software MAXQDA. Referring to the theoretical background and RQ 1, single assertions were classified according to whether theories or models were seen as being either tentative or certain constructs (deductive approach; Schreier 2014).

The following keywords guided the classification for theories or models as being tentative:

- Theories/models change, are modified, continue to develop, are not certain, are uncertain, do not exist in perpetuity, are rejected, are disproved, are not true/right/valid, are nothing fixed, are not facts, are not proven, can be caused to alter, do not function/work, and do not represent truth.

The following keywords guided the classification for theories or models as being certain:

- Theories/models are certain, do not change, do not develop any further, are (definitely) proven/verified, are fixed, remain permanently, and are right/true/valid.

Subsequently, subcategories were constructed on the basis of the interview statements, including conceptions about why a theory or a model can be seen as either tentative or certain (inductive approach; Schreier 2014). The transcription, editing, and structuring of the interviews included interpretations by the researcher, which could be supported by additional material (Gropengießer 2010), such as the concept maps. However, a detailed analysis of the concept maps (e.g., McClure et al. 1999) was not possible, because the requirements for a valid assessment instrument were not met (e.g., the method had not been previously carried out by the interviewees).

Another researcher coded three of the five edited interview transcripts, using the previously developed category system and a gradually developed coding guideline. This procedure is in line with the "consensual coding," which is similar to the computation of coefficients to determine interrater reliability and serves to improve agreement about the categories (Schmidt 2010; Schreier 2014).

The recorded interviews of the second cohort were not transcribed; however, the audio tracks were coded into the previously developed category system by means of MAXQDA and, where appropriate, new subcategories were created. Passages that were difficult to code were transcribed and discussed with another researcher.

Philosophers

The analysis of the subject matter followed the examination of the first cohort's interviews. Since the philosophers' statements are present in edited and published books or papers, they are already in a more clear and precise form. Consequently, only the selection of relevant passages and a content-related structuring in categories including philosophers' conceptions had to be performed (Gropengießer 2010).

Finally, preservice biology teachers' and philosophers' views were compared with each other in order to highlight differences, as well as commonalities.

Results

In a previous article (cf. Reinisch and Krüger 2014), which was based on the same interview survey of the first cohort described above, categories had already been specified. They addressed conceptions of the preservice biology teachers about (i) the terms "theory", "law", and "model"; (ii) the purpose and function of these three scientific knowledge forms within biology; and (iii) the relationship between theories and models. The preservice teachers' conceptions about theories included the notion that theories are used as in everyday language and as arbitrary constructions. Despite the broad variety of theories within the field of biology, the interviewees could only explicitly name the theory of evolution. Referring to the functions of a theory, the interviewees named the explanatory and predictive function but disregarded their descriptive function (cf. Lauth and Sareiter 2005). Models were seen as schematic representations of phenomena and were mainly characterized by their function, that is, simplifying, depicting, and explaining phenomena, imparting knowledge to others, and gaining new knowledge. The preservice teachers' conceptions about the relationship between theories and models can be called functional (Bailer-Jones 1999). Formalistic descriptions of models and theories (Bailer-Jones 1999) were not identified (cf. Reinisch and Krüger 2014).

The results derived from the interviews ($N = 10$) referring to the tentative nature of theories and models are presented (RQ 1). Subsequently, the philosophers' positions are formulated (RQ 2), and similarities between preservice biology teachers' and philosophers' conceptions are discussed (RQ 3).

Preservice Teachers' Conceptions (RQ 1)

Theories

Altogether, 11 subcategories refer to the tentativeness of theories in biology (Table 2). Some of these include conceptions in which the tentativeness is derived from the term theory itself or from characteristics assigned to theories (conceptual understanding). One example is the subcategory *mental constructs*: Theories are constructs that stem from someone's own thoughts and are the individual ideas of a person. Because of this they are seen as uncertain, tentative, and not proven. For example, Jasmin argued that a theory is uncertain because it presents an individual construct and, therefore, every human has his/her own theory. Other conceptions about the tentativeness of theories referring to a conceptual understanding can be located in the categories *fundamental uncertainty of theory*, *theories are based on observation*, *incomplete theory*, *theories exist in parallel*, *theories are partly changeable*, *verification of theories is not possible*, and *a theory awaits verification or falsification* (Table 2). There are also categories that mainly refer to the falsification, modification, or rejection of a theory due to the introduction of new knowledge or new results derived by testing the theory (procedural understanding). The focus is not on an understanding of the term theory but on external conditions, which are relevant for the development, change, or rejection of the theory. For example, the subcategory *falsification of theories* includes the conception that a theory needs to be changed or rejected if an experiment disproves the theory. The subcategories *model-based change of theory* and *changes in nature cause theory changes* reflect the views that the underlying model, or nature itself, changes—with subsequent influences on the theory (Table 2).

As with the tentative nature of theories, it seems that the notion about the certain nature of theories is sometimes directly connected to the notion of the term theory itself, or features of theories

Table 2 Tentativeness of theories: categories and preservice biology teachers' statements

Category Description	Evidence from interviews (interviewee)
Theories are tentative: conceptual understanding	
Mental constructs	
Theories are tentative because they represent different individual thoughts/ideas/beliefs. Theories are (just) ideas, thoughts, own conceptions about something	*In a theory there is no certainty, because a theory is something that someone has thought of* [...] *someone's personal line of thought.* (J)
Fundamental uncertainty of theories	
A theory is not perfect by principle, and subject to permanent change. Reasoning for the tentativeness evolves out of the term theory itself ("it is just a theory"). Theory itself means uncertainty and changeability.	*For me, a theory does not have to be final. It is just a theory.* [...] *It does not matter how controversial it is or how stable it is* [...]. *What is important to me is that a theory just means that there is still scope.* [...] *So, it is always a permanent change.* (J)
Theories are based on observation	
Theories are nothing fixed because they are considerations only based on observation.	*By observing you can postulate a theory, how it could be. For example, when I am observing the behavior of certain animals. I am sitting in the forest, I am looking at how they interact and now I am able to establish theories and can consider, "What is at the bottom of it?" Then you have a theory, but this is not really something fixed.* (P)
Incomplete theory	
A theory is not complete because not all aspects about the phenomenon are/can be explained by or included in the theory.	*But there are other perspectives and these have not been considered in that case. So there are other things that are not explained by this theory.* (J)
Theories exist in parallel	
There can be several theories about the same phenomena parallel. Possibly one theory takes over another.	*I can have my theory and someone else can have his theory and they can exist parallel because I can't assume that my theory will be proven.* (A)
Theories are partly changeable	
Some parts of a theory are still subject to change, some parts of the theory are true/set (sometimes called a law).	*Concerning the theory of evolution there are still several steps missing* [...]. *Thus, it could be said that the sequence of the theory of evolution* [...] *is still theory. That changes at times, too. But that everything evolved out of each other, that not everything was suddenly there, that you can set as a law.* (P)
Verification of theories is not possible	
Theories are not certain, because it is not possible to prove them 100 % and/or they are not provable on principle. Further reasons might be named: - The phenomenon lies in the past and is not provable anymore. - The phenomenon is located on the micro level and is, therefore, not visible.	*Theories are assumptions that are based on certain foundations, but cannot be 100 % proven as yet.* [...] *That is why it is difficult to verify* (*evolution*) *theory. So you can support it by indications, but you cannot say, "That is it, that is a fact. Yes!" It is not like that.* (A)
A theory awaits verification or falsification	
The uncertainty/tentativeness of theories results from the fact that they can be proven or disproven.	*Because you can prove and disprove a theory and everything is still open, there is no certainty.* (J)
Theories are tentative: procedural understanding	
Falsification of theories	
Theories can get disproven/falsified. This is considered to be due to new knowledge/discoveries, hypothesis-based testing and/or the implementation of studies, examinations, new research methods, experiments, or observations.	*A theory will be altered if, perhaps, one develops new research methods, which make it possible to observe something that was not possible to observe before.* (L)
Model-based change of theory	
A theory needs to be changed if the model derived from the theory does not function/gets disproven in the concrete application (of the theory).	*I establish a theory and I make a model and I see that it fails to work out. When I make a model of a little ecosystem, of decomposers and so, for example, and see* [...]*—it is illogical—that they don't decompose, but eat each other, then, I can see in my model, in my little terrarium: Something is wrong with my theory.*" (H)
Changes in nature cause theory changes	
Because nature changes, theories change as well.	*I would relate* [...] *this* [*to*] *'how certain they* [refers to laws, models and theories] *are,' that everything in nature permanently undergoes change and, therefore, that you probably cannot predict this. Also, because you do not know how, for example, all these climatic conditions change and what laws might shift or what new impacts can be effective with which these things can change.* (P)

Table 2 (continued)

Category Description	Evidence from interviews (interviewee)
Theories are certain: conceptual understanding	
Verification of theories	
A theory is already verified/proven or can be verified/proven ("not yet proven") in future.	*Theories are verified hypotheses. For example, the theory of evolution is a theory that is proven, there is proof for this theory. So in the broadest sense,* (*a theory*) *is a concept that is proven.* (L)
Proven theories are laws/facts	
A theory that gets proven is not called a theory anymore but a law/fact. Theories develop to laws. These are considered to be true/certain.	*Most often, eventually laws develop out of theories that you have, when you find proof for it. So you do not wake up one morning and develop a law.* [...] *I would almost say that theories can develop in to laws.* (A)
Certain under conditions of construction	
Theories are valid when they are made and under the conditions under which they were constructed.	*These* [...] *theories are valid under exactly the same conditions they were made in.* (P)
Theories explain	
Theories are proven if they explain something in a reasonable way.	*First, it* [*model/theory*] *is considered to be proven if it explains something in a way that makes sense.* (C)
Theories are certain: procedural understanding	
Testing strategies to prove theories	
Theories are certain because they are tested. Different methods and testing strategies include: - Repeated testing, interdisciplinary testing by several scientists - Testing through: the implementation of a study, logic, a model, an experiment, and an observation	*I would perform the experiment in any case at least two times and if it fits to my hypothesis I can—at the very least—consider my theory as supported. Whether I consider it as being proven depends on whether I have already done ten experiments that all support my theory. Then I can slowly assume that my theory is considered to be proven.* (A; repeated testing)

Square brackets indicate the omission of statements or the inclusion of additional words to enable better understanding. The original statements made by the interviewees were in German and linguistic flaws may have been caused by the translation

(conceptual understanding). The conception *proven theories are laws/facts* includes the idea that a theory changes its label to law/fact when it is finally proven. A theory is seen as something certain, which is ever true, but once it has been proven, it is no longer called a theory. Equally, the conceptions *verification of theories*, *certain under conditions of construction*, and *theories explain* refer to an understanding of what constitutes a theory. On the contrary, the subcategory *testing strategies to prove theories* presents a position that refers to external conditions that lead to the acceptance of a certain theory (procedural understanding). For example, the use of an experiment allows acceptance of a theory as certain. This can be seen as the opposite of the *falsification of theories* subcategory. In one case, an experiment is seen as the reason for the certainty and, in the other case, for the tentativeness of theories. However, both describe the influence of an external influence (i.e., an experiment) on the status of a theory (Table 2).

Models

In total, ten subcategories refer to the tentativeness of models (Table 3). Some of these categories also include an understanding of what constitutes a model (conceptual understanding). For example, *degree of simplification* includes the notion of models being simplified entities. This category includes the idea that a very simplified model is less certain than a less simplified model. Other conceptions about the tentativeness of models are related to the nature of models themselves and can be located in the categories *verification of models is not possible* and *an exact true model would be reality*. Seven subcategories refer to external conditions that lead to the change or rejection of a model (procedural understanding). The conception *application of models* includes the notion that the application of a model in a new context and the associated testing of a model could potentially cause the model to be changed. Other categories here are *insufficient understandability*, including the idea of people being responsible for the tentative nature of a model, *falsification of models*, *role of model builder, missing fit to theory*, *law-/theory-based change of models*, and, likewise as for theories, *changes in nature cause model changes*.

Six subcategories of the main category *models are certain* include characterizations of a model (conceptual understanding). *Mesocosm* refers to the relationship between some models and their context in reality, that is, the phenomena. If the latter can be looked at, the model is considered to be certain. Therefore, the certainty is restricted to only some models. Another example is the subcategory *dependency on context*, which refers to another restriction related to the context in which a model is embedded. Within these specific contexts, models are seen as certain. The subcategories *verification of models*, *models explain*, *models as enduring constructs*, and *idealization* also include conceptions about the nature of models (conceptual understanding). Two subcategories include external factors that are responsible for the certainty of models (procedural understanding): The first one, *conservatism*, includes the role of scientists working with the model and influencing its enduring stability. The second one, *testing to prove models*, includes a general or specific testing procedure that is applied to the model (Table 3).

Finally, there is one subcategory that cannot be clearly classified into one of the main categories: *Models are more certain than theories*. This includes the idea that certainty increases from theories to models. Two reasons were given for models being more certain than theories: Firstly, "because [the model] is already the way to the law. But it still does not have so much [validity as the law]" (Jasmin) and, secondly, "because [a model] tries to explain something. Well, the theory as well, but then a model tries to depict it. It is a little bit more special, so more specific. A model is somehow more solid. So you cannot change it that easily" (Jasmin).

Philosophers' Conceptions (RQ 2)

Although the position of Francis Bacon (1620/1990; novum organum, I, especially 14, 19, 22, 50, 70, 95, 99, 100, 105, 106; novum organum II, especially 10–13, 15) is not explicit on theories or models, his work has contributed significantly to science philosophy and formed the foundation for much subsequent research (e.g., by philosophers of logical empiricism). His conceptions were also strongly criticized and revised (e.g., by Popper). Furthermore, he introduced the phrases "induction" and "experimentation" in the context that they are still used today.

- **induction*[4]: inference from specific experiences (i.e., observations) to general conditions of genesis/existence of a phenomena in nature; hereby, no contradictions to the inferred explanations are allowed; collection and organization of experiences leads to certain knowledge.
- **experimentation*: collection of experiences can be made through specific changes to the conditions in which a phenomenon occurs.

[4] In the running text, philosophical conceptions are marked with an asterisk to allow easier differentiation between them and preservice teachers' conceptions.

Table 3 Tentativeness of models: categories and preservice biology teachers' statements

Category Description	Evidence from interviews (interviewee)
Models are tentative: conceptual understanding	
Verification of models is not possible	
Models are not certain, because it is not possible to prove them 100 %.	*However, in principle I can never say that because I never know if* [*the model*] *is final now. I cannot prove that it is like that and not different.* (E)
Degree of simplification	
Certainty depends on the degree of simplification: The more simplified a model, the less certain it is.	[...] *the model depending on the extent it is simplified or not is certain or not certain.* (P)
An exact true model would be reality	
There is no certain model because if a model represents the exact truth, it would be reality itself. The purpose that a model fulfills, i.e., to simplify something, would get lost.	*As soon as you represent the exact truth, it would not be a model for me anymore, but the actual circumstance. If I would always represent it exactly as it is in reality, then I would not need models to visualize [reality] and make it easier for me to understand.* (P)
Models are tentative: procedural understanding	
Insufficient understandability	
A model would be revised, in case the models' content is not accessible to the students via the model.	*I realize quickly, when students in school or at university do not understand it despite the model.* [...] *Maybe I think about another model or concept model by myself and teach it to them this way. So a model is something you can rather revise in the case of teaching.* (E)
Falsification of models	
Models can get changed due to new or future knowledge and/or the application of new research methods. Further research/knowledge is necessary. Not everything is known yet.	*New knowledge appears just because of new methods,* [*for example,*] *to filter some substances, or something new gets discovered or so on. Then, many theories or models are not sustainable anymore.* (H)
Application of models	
Models get redeveloped/changed because they got disproven/do not function in the case of applying/testing/transferring to a new context.	*Models can be changed if they are applied to contexts and you ascertain that they do not really work. Something about the model has to be modified, then you can rethink a model.* (L)
Role of model builder	
The certainty of a model depends on the model builder. Models are, among others, based on subjective beliefs and, therefore, should be seen as tentative.	*Models* [...] *get developed on the basis of any knowledge whatsoever by humans and it is partly influenced at the individual level and thus it is not something final.* (F)
Missing fit to theory	
A model gets further developed if it differs from the corresponding theory.	*I set up a model and I see that it, perhaps, differs from the theory* [...] *and then I expand the model.* (H)
Law-/theory-based change of model	
Models have to be changed when the underlying law/theory changes.	*Although models are always there to reflect laws of nature and if these change, the models just change as well.* (M)
Changes in nature cause model changes	
Because nature changes, models change as well.	Table 2: Changes in nature cause theory changes
Models are certain: conceptual understanding	
Verification of models	
A model is already verified or can get verified.	*In the case of some models* [...] *that are close-meshed and already proven I do not think that they will change that much anymore.* (H)
Models explain	
Models are proven, if they explain something in a reasonable way.	Table 2: Theories explain

Table 3 (continued)

Category Description	Evidence from interviews (interviewee)
Models as enduring constructs	
After falsification (e.g., through new insights), models continue to exist and are not modified. Instead, a new model will be constructed.	*You construct this model on the basis of data and analyses and this model remains permanently. Later on, if it gets disproven or there are innovations, then this model still continues to exist* [...]. *The following model builds on it or criticizes the preceding model in a particular way.* (F)
Mesocosm	
Models whose original could be looked at are certain.	*Models are very accurate and reliable, because you spring from, for example, a model of the heart. Because nowadays you are or were able to look at a real heart and to reconstruct a heart in detail.* (M)
Dependency on context	
Models are certain and reliable only in specific contexts. Within these limits, they can be applied in a safe way.	*Models usually are suitable in very specific contexts.* [...] *That is, they reach their limits quite quickly. You often have to use different models. As long as you know about it and take account of it models are very certain and very reliable in these contexts.* (A)
Idealization	
A model is, in principle, always stable because what it describes is essentially the same, even if there are deviations.	*There are hearts, for example, that are oversized and pathologically changed. That is something one could also argue: "This is not so realistic and it does not really describe the real heart, because there are also other hearts." But after all it is stable in principle.* (M)
Models are certain: procedural understanding	
Conservatism	
Although data suggest the changing of a model, researchers insist on their model due to research traditions.	*Scientists are rather ambivalent* [*concerning the problem that you cannot transfer everything from a model*] *because there are some of them who insist on that model. They grew up with it in research and insist on that model being generally valid and try to explain it over a thousand corners why it is still generally valid.* (E)
Testing to prove models	
Models are certain because they are tested. Different methods and testing strategies include: - Interdisciplinary testing by several scientists. - Testing through application of the model.	[*A biological model, theory, and law are considered to be proven*] *if a problem gets* [*investigated*] *by several scientists, maybe not only from biology, but maybe connected with chemistry or if, depending on what is still missing, really every element is covered by the scientists and, yes, you always achieve the same result that only this one circumstance is possible.* (P)

Square brackets indicate the omission of statements or the inclusion of additional words to enable better understanding. The original statements made by the interviewees were in German and linguistic flaws may have been caused by the translation

Reichenbach (1930a) was one of many proponents of logical empiricism, a philosophical movement most prominent in the 1930s, and also described the "principle of induction" and extended it by means of the concept of probability (Reichenbach 1930b):

> We called the principle of induction the instrument with which to decide upon truth in science. To be precise we have to say that it serves for the decision of probability. […]

for scientific propositions there are continuous levels of probability, whose unachievable upper and lower border are truth and falsity. (p. 186)

Theories

Nuzzo (1999) describes in the *Enzyklopädie Philosophie* an explicit difference between scientific theories and theories in everyday language, outlined in Table 4.

Popper (1934/1971) introduced critical rationalism (also called falsificationism), which is regarded as one of the most recognized views on scientific theories. His approach focused on theories as basic units of science, and the revision of scientific claims and theories instead of progress by means of generalization of claims (**induction*; see above), as had been done by proponents of positivism and logical empiricism (e.g., Reichenbach 1930a, see above). Popper's work was based on the method of falsification and differentiated between scientific and non-scientific theories, depending on the existence of a falsification of theories (demarcation criteria; Table 4). It is remarkable that Popper did not provide an explicit and concise definition of theory (Wiltsche 2013). Also, he did not clearly distinguish between the phrases "theory", "hypotheses", and "system".

Lakatos' (1977/1982) research program approach can be seen as a further development of Popper's falsificationism and also included some of Kuhn's (1962/2012) paradigm concept.[5] Lakatos' critique of Popper's approach, which he calls naive falsificationism, focused particularly on the missing connection to real scientific practice. Despite a falsification, researchers do not instantly reject a theory but rather construct additional hypotheses that "rescue" the whole theory. Lakatos also criticized Popper's use of theory as a basic unit of science but rather suggested reflecting on a series of theories, called a "research program." This consists of a hard core and the auxiliary belt. This approach was also based on a specific methodology, which not only serves as support for handling theoretical or empirical anomalies but also includes the role of scientists in the development of scientific knowledge (Table 4).

Despite the widely held acceptance of Popper's falsificationism and Lakatos' research program approach across all of natural sciences, both of them either wrote about scientific theories in general or provided examples from the physics domain. In contrast, Hoyningen-Huene (2013) referred to all sciences, including biology (e.g., theory of evolution). His views are presented in Table 4.

Models

Until the middle of the nineteenth century, the notion of certainty in respect to scientific knowledge existed. Subsequently, the idea of absolute certainty slowly disappeared (Hoyningen-Huene 2013). Since scientists and philosophers recognized the use of models in a scientific context at the beginning of the twentieth century (Bailer-Jones and Hartmann 1999), it can be concluded that there are only positions about the tentative nature of models.

[5] Kuhn (1962/2012), representing one of the most prominent (historicist) views on science, is radically opposed to Poppers' methodological approach highlighting scientists' as well as even science policy's role for the continuance of so called paradigms (including theories). Since a more moderate view about the role of scientists and science community is also taken up by Lakatos, Kuhn's view is not included here.

Table 4 Philosophers' positions about theories with reference to the sources used

Philosophers' literature	Category	Description
Enzyklopädie Philosophie, Nuzzo (1999; col. 1620b-1624b), GER	Everyday theory	Abstract uninteresting speculation; pure intellectual and even partly a fictitious and arbitrary construction, also in the sense of a sheer presumption or fantasy; are seen as unrealistic, useless, and only schematic perceptions
	Scientific theory	Main information support of scientific knowledge; characterized by generality; comprehensive systems of justified propositions that—as the result of the generalization and systematization of many empirical data and observations—provide explanations for certain facts and phenomena.
Popper (1934/1971; pp. 3–28), GER	Induction is inadmissible	Inductive procedures and conclusions do not exist, i.e., scientific reasoning from data (e.g., achieved by experiments or observations) to theories is logically inadmissible.
	Verification is not possible	Theories cannot be verified, because it is not possible to investigate every case derived from a theory.
	Deduction	The aim of science is to test deductions of theories in order to falsify the theory; a single counter-example is sufficient.
	Falsifiability of scientific theories	Only falsifiable theories can be considered to be scientific.
	Non-falsifiability of non-scientific theories	Theories that cannot be considered as falsifiable are theories of "pseudo"-science or called "metaphysical."
Lakatos (1977/1982; pp. 31–52), GER	Hard core	Develops in a slow and long tentative process of trial and error; is then the identity-establishing basic idea of the program; constant and irrefutable; e.g., laws of motion and the law of gravity within theory of gravity
	Auxiliary belt	Additional theories "around" the hard core are subject to change because of problems internal to the theory or because of empirical problems.
	Negative heuristics	Methodological decision of researchers to protect the hard core, in which everything that is contradictory to the hard core, e.g., contradictory observations, have to be redirected to the auxiliary belt.
	Positive heuristics	Provide researchers with specific problem-solving techniques that help to modify the auxiliary belt in order to anticipate falsification of the hard core.
	Comparison of research programs	A research program can be dismissed if and only if there is another research program it can be compared with; if the new research program has more heuristic/explanatory power and shows more progressive development, the original one will be dismissed.
Hoyningen-Huene (2013; pp. 59–61, 83–84, 94–98)	Systematic theories	Scientific theories are characterized by their high degree of systematicity.
	Unsystematic theories	Everyday theories are characterized by their looseness; provided explanations "are often vague, sketchy, certainly not quantitative, and stand more often than not on dubious epistemic grounds" (p. 61).
	Varying degree of hypothetical character	Degree of the hypothetical character reaches from pure speculation with (almost) no supporting evidence to theories that are considered to be facts, e.g., theory of common descent.

The abbreviation GER marks literature that was analyzed in the German language

Three out of the four analyzed philosophical positions (Bailer-Jones, Giere, Hoyningen-Huene) referring to models include the notion of models as being inaccurate and simplified entities. Therefore, this one common conception is expanded on in Table 5.

Today the function of models as a means to gain new knowledge is unquestioned (e.g., Hoyningen-Huene 2013). However, in the first half of the twentieth century, models were seen only as supplementary to theories (Carnap 1939). The most recent approach to models in science philosophy and also one recommended for science education is the "semantic view" (Adúriz-Bravo 2012; see above). One proponent of the semantic view is Ronald Giere (1988, 1999, 2001), who included examples of biology in his work (e.g., the model of DNA by Watson and Crick)—in contrast to other authors of the semantic view, who mainly described examples from physics. For Giere, the main purpose of models within the empirical sciences was their function as tools to represent the world (e.g., maps, diagrams, scale models; see Table 5). According to Giere, there cannot be a final decision about the correspondence between a model and the real world. However, there can be good reasons for the fit of a model to the real world. Giere (2001) claimed: "The goal of any evaluation is to reach a judgment about the fit of a model to the world based on the evidence presented" (p. 25; Table 5). Giere offered different outcomes of the examination of models (negative evidence, positive evidence, evaluation of multiple plausible models; cf. Giere 2001).

Another proponent of the semantic view was Bailer-Jones (2002, 2004, 2009), who argued that the model itself could not be described as being true or wrong in reference to the empirical world, but the propositions derived from a model are either in agreement with the world or not (Table 5). Further, Bailer-Jones highlighted that despite the observation that sometimes models' propositions are not in agreement with the empirical world, these models are still used or they represent phenomena adequately. For this, she identified several possible reasons, which are either pragmatically or epistemologically motivated (cf. Bailer-Jones 2004). One reason for the latter refers to the model user (Table 5). Additionally, Bailer-Jones highlighted a revised understanding of theories against the background of models (Table 5), since philosophers have recognized the high value of models—instead of theories—for the description and analyses of scientific phenomena (see above).

Hoyningen-Huenes' (2013) briefly presented views about models are guided by their predictive function. The author defines models by their application when "systems are too complex to be treated by theories or general laws" (p. 85; Table 5). In his work, Hoyningen-Huene also devotes himself to the representation of knowledge by models as an additional function. One example is the DNA model by James Watson and Francis Crick. The final DNA model served as the basis for a prediction concerning the copying mechanisms for genetic material: "Watson and Crick's model clearly represented biologically relevant knowledge of a certain molecular structure [...], that, due to its specific visual quality, can be grasped quickly and accurately" (p. 146). Although the example is considered as a model, in the context of representing a body of knowledge in a systematic and visual way, it could be also called a representation.

Vollmer's (1975b) evolutionary epistemology approach is of a more general nature but has been adapted to models by other authors (e.g., Mikelskis-Seifert and Fischler 2003). Some conceptions of his approach are included here due to the similarities to preservice biology teachers' conceptions. Vollmer's approach includes the view that the human brain did not primarily develop as a tool for cognition but for surviving and is, therefore, a product of biological evolution. In order to adapt to the world, human minds and sensory organs, which are the tools for cognition, 'fit' to the aspects of the world that can be perceived (called the mesocosm; Table 5).

Table 5 Philosophers' positions about models with reference to the sources used

Philosophers' literature	Category	Description
Giere, Bailer-Jones, Hoyningen-Huene (see below)	Limited accuracy	The perfect model would be the original (i.e., phenomenon, system, real world) itself; therefore, models describe the empirical reality only inaccurately, because they are based on approximations and simplifications.
Giere (1988; pp. 78–90) Giere (1999; pp. 41–57) Giere (2001; pp. 21–33)	Isomorphism is not possible	Isomorphism is not possible because there is no reasonable model to literally show an isomorphism with features of the real world.
	Similarity depends on context	Degree of similarity between the model and the real world depends on the context and the interest of the model builder and users, who define the context, e.g., spatial and structural similarities have been important in the case of the DNA model.
	Direct examination of the model fit is not possible	There cannot be a direct comparison of a model and the real world because objects of the latter are mostly too large, too small, too remote, or too complex.
	Indirect examination of the model fit	The model and the real world are compared indirectly by a physical interaction (experiments, observations) with the objects of the real world system; results of the interaction, the data, are then compared with model-based predictions; model fit can be judged by the outcome.
Bailer-Jones (2002; pp. 1−11), GER Bailer-Jones (2004; pp. 201−221), GER Bailer-Jones (2009; pp. 177−204)	Testing a model	Testable agreement of the propositions of a model with empirical data is central in order to gain knowledge about the world; by obtaining these data, models get further tested and ideally further confirmed.
	Changing a model	A model is not static; it changes and gets replaced by a more successful model due to the latest data and changes in information to which the model refers; by this, the model stays meaningful in reference to the phenomenon.
	Model fulfills the function	Agreement with empirical data fades into the background when there is an optimal fulfillment of function by the model; to fulfill the function, only certain propositions have to be true.
	Role of model user	Only a model user can decide, in respect to the selection of the represented aspects of the phenomenon and the functions a model has to fulfill, which incorrect propositions can be tolerated and which cannot.
	Application of models	Models serve as mediators between theories and the empirical world; to apply a theory to a specific real world phenomenon means to develop a model, while adjusting the theory to the empirical conditions of the phenomenon; it follows that the theory is only empirically testable by means of models.
Hoyningen-Huene (2013; pp. 85−87)	Correctness of model is not necessary	A model of a system does not necessarily have to be right and correct; moreover, additional simplification and assumptions can actually be false.
	Predictive power	The predictive power of a model can be increased or even made possible by assumptions based on the model; in this case, a "false" model is legitimate.
Vollmer (1975b; pp. 100–132), GER	Mesocosm	The world of medium dimension: the segment of the world that humans are able to perceive and interact with; outside of the mesocosm are foremost very small things (e.g., molecules), big things (e.g., universe), or complicated systems (e.g., human brain)
	Tool for perception	Scientific knowledge exceeds the mesocosm by reference to very small, big, or complicated systems; for this, scientific tools such as models aid perception.
	Truth is not achieved by visualization	Visualization is no criterion of truth, i.e., you cannot rate something to be true or wrong, irrespective of whether or not it can be visualized.

The abbreviation GER marks literature that was analyzed in the German language

Correspondences Between Preservice Biology Teachers' and Philosophical Conceptions (RQ 3)

Theories

A comparison of the philosophers' and preservice teachers' conceptions (Table 6) revealed similarities in the differences between scientific and everyday theories when using the Enzyklopädie Philosophie. In particular, within the subcategories *mental constructs* and *fundamental uncertainty about theories*, an understanding of a theory in biology is similar to the description of **everyday theory*. Hence, within these conceptions, the everyday meaning of theories is used instead of a scientific meaning. It is suggested that within educational settings, preservice biology teachers should establish an understanding of a **scientific theory* that differs from an understanding of an **everyday theory*. It is assumed that if the distinction between both kinds of theories is understood, the role and status of the two different types of theories will be acknowledged in a way that is more like the views in philosophical literature. However, concerning Hoyningen-Huene's view about the **varying degree of hypothetical character*, there is conflict with **scientific theory* (Enzyklopädie Philosophie), since the philosopher also considers pure speculations as theories, as long as they possess a high degree of systematicity.

Lakatos' conceptions of the **hard core* and the **auxiliary belt* within a research program have similarities to the preservice teachers' subcategory *theories are partly changeable* (Table 6). In particular, both described something set and unchangeable, which is either not specified or was called "law" in the interviews and "hard core" by Lakatos (exemplified by Newton's laws of motion and law of gravity). In the interviews and as stated by Lakatos (**auxiliary belt*), there is something uncertain which can still be changed or rejected. To some extent, there is also a resemblance with the subcategory *incomplete theory*, since the further development of the **auxiliary belt* includes the idea of an expansion of a theory and, therefore, a former incomplete theory. However, no further explanations were offered in the interviews with the preservice teachers.

Contrary to the preservice teachers, Lakatos also included the idea of intentional and conscious behavior of scientists, which is the protection of the **hard core* by **negative heuristics* and the redirection of problems to the auxiliary belt with **positive heuristics*. Lakatos' approach can be seen as an alternative approach to avoid the often-criticized views by Popper, according to which a theory can be rejected by just one experimental result, and to give learners a view of science that includes progressive processes. Lakatos also emphasizes that there is still the possibility of rejecting a whole research program in the case of the existence of another more progressive research program (**comparison of research programs*). Within the subcategory *theories exist in parallel*, the presence of parallel theories is highlighted. Contrary to Lakatos, the preservice teachers gave no explicit further reasoning for the progression of one theory and the degeneration of another theory.

The preservice teachers' rejection of theories as verifiable entities (*verification of theories is not possible*) corresponds to Popper's view (**verification is not possible*; Table 6). Some of the interviewees expressed an understanding about theories that was similar to Popper's, referring to the assumption that a theory is not provable in principle. The participants did recognize an important view within science (philosophy), including the impossibility of verification of a theory, because in natural science it is impossible to investigate every case derived from a theory.

The subcategories *a theory awaits verification or falsification* and *falsification of theories* also have similarities with Popper's **falsifiability of scientific theories* (Table 6). In all conceptions, the possible falsification of a theory is assumed. However, the stated conceptions by the preservice teachers are not as detailed as those Popper proposed. Specifically, Popper's conceptions included in the subcategories **induction is inadmissible* and **deduction* do not become apparent. The interviewees did not acknowledge the value of scientific theories in relation to non-scientific theories (**falsifiability of scientific theories* in comparison to **non-falsifiability of non-scientific theories*).

Three of the identified conceptions that refer to the tentativeness of theories do not feature correspondences with the philosophers' positions about theories (Table 6). The conception *model-based change of theory* includes the perspective that the tentativeness of theories relies on the changing nature of models, which includes the concrete application of the theory to the real world. In philosophical literature about theories (see Table 4), the role of models within theory construction is often neglected. On the contrary, authors of model literature do not only focus largely on models but also highlight a revised understanding of theories against the background of a model-centered view of science (Bailer-Jones 2004, 2009). Models serve as a mediator between theories and the empirical world. The application of a theory to a specific real world phenomenon means developing a model while adjusting the theory to the empirical conditions of the phenomenon. Therefore, the theory is only testable by means of models (**application of models*; Table 5). Comparing the preservice teachers' and Bailer-Jones' conceptions reveals a high correspondence. The preservice teachers' reasoning resulted in specific examples to illustrate their conceptions (one example can be seen in Table 2).

The subcategory *theories are based on observation* relates to the preservice teachers, since none of the philosophers referred to a differentiation between observations and other scientific methods in reference to scientific theorizing. As Kohlhauf et al. (2011) state, "most people believe that they know what 'observation' and 'perception' mean, because they do it all the time in order to make sense of the world" and "the process of observing […] is not seen as a serious independent scientific research method" (p. 667). However, this view is not scientifically adequate, as a look into scientific practice reveals that the method of observation is also a reliable method to gain and test knowledge (Bortz and Döring 2006; Kohlhauf et al. 2011). For example, McComas (2002) references Darwin's work, which consisted of comprehensive observations without any experimentation. This resulted in a major contribution to the theory of evolution, which is, nowadays, widely accepted by scientists.

The conception *changes in nature cause theory changes*, which corresponds with *changes in nature cause model changes*, can be seen as an interesting view since it is assumed here that inherent characterizations and principles of nature itself can change. None of the philosopher analyzed here expressed any views about this. In addition, learners should reflect whether it is even possible that fundamental principles of nature will change or whether it is our view and perspectives that change.

The subcategories *verification of theories* and *proven theories are facts/laws* include the notion that a theory can be proven. Theories are seen either as something unchangeable or as being unchangeable at some point in the future. The latter subcategory differs from the first one, since proven theories are not called theories anymore but laws or facts. This is in line with results of other studies, in which the conception dominates that proven theories become laws (cf. McComas 2002). However, here, it is central that theories are seen as something provable.

Table 6 Comparison of preservice biology teachers' and philosophers' conceptions about theories

Preservice biology teachers' conceptions of theories		Philosophers' conceptions of theories	
		(Partly) similar conceptions	Additional conceptions
Theories are tentative	Mental constructs Fundamental uncertainty about theories	Everyday theory	Scientific theory Systematic theories Unsystematic theories Varying degree of hypothetical character
	Theories are partly changeable Incomplete theory	Hard core Auxiliary belt	Negative heuristics Positive heuristics Comparison of research programs
	Theories exist in parallel	Comparison of research programs	
	Verification of theories (models) is not possible	Verification is not possible	
	A theory awaits verification or falsification Falsification of theories	Falsifiability of scientific theories	Non-falsifiability of non-scientific theories Induction is inadmissible Deduction
	Model-based change of theory	Model conception: application of models	
	Theories are only based on observation Changes in nature	No correspondences between preservice biology teachers' and investigated literature of the philosophers	
Theories are certain	Verification of theories (models) Proven theories are facts/laws Certain under conditions of construction	Induction	Verification is not possible
	Theories (models) explain	Comparison of research programs	Consolidation: comparison of research programs
	Testing strategies to prove theories	Everyday theory Scientific theory Induction Experimentation Hard core	Verification is not possible Negative heuristics Varying degree of hypothetical character

This shares parallels with Bacon's idea of **induction*, in particular, his idea of the existence of certain knowledge. Similarly, the subcategory *certain under conditions of construction* can be seen as being related to this. However, the preservice teachers' conception remains quite vague. In conclusion, falsifiability on principle (Popper's **verification is not possible*) is not acknowledged within these conceptions.

The conception *theories explain* connects the explanatory function of theories (Lauth and Sareiter 2005) with the proven status of theories. Despite being vaguely formulated in the interview (the assertion in Table 2 is the only one), it can be compared to Lakatos' **comparison of research programs*, which includes the importance of high explanatory power as being essential to successful theories. However, it must be stated that the philosopher uses this to reason for the displacement of one theory in favor of another with greater explanatory power.

The preservice teachers identified different ways of testing theories in order to prove them (*testing strategies to prove theories*). Although the notion of theories needing to proven is in stark contrast to the conception of an **everyday theory*, some characteristics of a **scientific theory* (justified propositions, role of observations; Table 6) are met with the opposite occurring. The principle of falsifiability, named by Popper (**verification is not possible*), is not acknowledged within these conceptions. Strong correspondences are present in reference to Bacon's ideas of **induction* and **experimentation*, specifically the experimental approach named by the preservice teachers in order to prove a theory and, therefore, achieve a construct of certain knowledge. The idea of certain knowledge can, however, be considered as an outdated and untenable view, ever since Popper proposed his conceptions of falsification (Table 4; see also Hoyningen-Huene 2013). Lakatos' and Hoyningen-Huene's views are also referenced to some degree by the preservice teachers' views. In particular, Lakatos acknowledged that at least some parts of a theory, which he calls a research program, should be set and stable (**hard core*). However, he highlighted the role of scientists in protecting the research program (**negative heuristics*)—a conception that did not occur in the interviews. Hoyningen-Huene even stated that some theories are considered to be facts (**varying degree of hypothetical character*) but does not provide explanations under which conditions this occurs.

Conceptions by Hoyningen-Huene, referring to a difference between scientific and everyday theories by means of the degree of systematization (**systematic theories*; **unsystematic theories*) were not referenced in the interviews and only seem to be fundamental to the philosopher's views.

Models

The subcategory *verification of models is not possible* is comparable to *verification of theories is not possible* and can also be compared to Popper's view (**verification is not possible*; see above), even if he did not explicitly reflect on models but only on hypotheses and theories. In particular, the principle of falsification and categorical denial of the principle of verification is regarded as universally applicable with regard to scientific assertions—although often criticized in conjunction with scientific theories.

The subcategory *degree of simplification* has some similarities to the philosophical notion that models are simplified entities (**limited accuracy*; Table 7). However, the preservice teachers' analysis showed that this is also connected to the view that a very simplified model is less stable and reliable than a less simplified model. Hoyningen-Huene differentiated between the terms representation and model and used them in different ways. A representation serves to represent or show knowledge systematically and visually. A model is a word he used in connection with the use of models as predictive tools (**predictive power*). He argued that a model does not have to be accurate (**simplification*) or even right (**correctness of model is not necessary*). Similarly, neither Bailer-Jones nor Giere stated that a simplified model is less stable than a more realistic one. On the contrary, Giere highlighted that models are not supposed to show a phenomenon in a realistic way (**isomorphism is not possible*).

Giere's rejection of an isomorphism between a model and the real world (**isomorphism is not possible*), as well as the conception of a **limited accuracy* of models, shares similarities with the preservice teachers' subcategory *an exact true model would be reality.* The preservice teachers also highlighted that models do not have a one-to-one relationship with the real world. Contrary to Giere they reasoned that because of the simplified nature of models, a model can never be a final or certain product. The difference between the preservice teachers' and Giere's conception concerns the purpose designated to models. While the former highlighted the illustrative function of models, the latter emphasized the predictive power of a model and claimed that a judgment about the fit between model (i.e., predictions derived from the model) and real world (i.e., data) needs to take place (**indirect examination of the model fit*).

The subcategory *falsification of models* corresponds to Bailer-Jones' **changing a model*. Both stated that a model is dynamic in nature and needs to change or be replaced when new information or data emerges.

Bailer-Jones' **testing a model* and Giere's idea about the **indirect examination of the model fit* are similar to the content of the subcategory *application of models*. There is a difference concerning the comparison between a model and its counterpart in the real world. Whereas the preservice teachers outlined a direct application of the model to the world, the philosophers stressed an indirect comparison of both. Bailer-Jones suggested an evaluation of the agreement between the empirical world and the propositions derived from a model (**testing a model*), and Giere outlined an evaluation of the fit between data, achieved by means of experiments or observations, and predictions derived from a model (**indirect examination of the model fit*). In some preservice teachers' interview statements, the use of experiments was included. An explanation of how the model is applied to the real world was, however, not given as can be seen by Leon's assertion "if [models] are applied to contexts and you ascertain that they do not really work" (Table 3).

An aspect Giere included in his conception of **similarity* and which was also emphasized by Bailer-Jones (**role of model user*) is the role of model builder and users. They define the context in which a model is used (Giere, Bailer-Jones) and decide whether incorrect propositions derived from the model can be tolerated or not (Bailer-Jones). The analysis of the preservice teachers' interviews also showed that the model builder is taken into account (*role of model builder*). However, in a less specific way, the construction of models is seen as a human enterprise including subjective components. It was not explained further in which specific ways personal beliefs influence the model-building process.

Four of the preservice teachers' conceptions that refer to the tentativeness of models did not share direct correspondences with the philosophers' positions, with one of them, *change in nature cause model changes*, being outlined in the theory section above. The subcategory *insufficient understandability* seems to be characteristic of the preservice teachers. Although none of the philosophers here included a comparable approach, Hoyningen-Huene (2013) included a similar idea in conjunction with representations and not models. In particular, he differentiated between models being used for the prediction of something and representations being used for the systematized presentation of relevant knowledge. This can include the possibility that the same entity can serve as a model and a representation at the same time (e.g., Watson and Crick's DNA model). In regard to representations, he did not state anything about the tentativeness; however, it is conceivable to change a representation of something if it cannot "be grasped quickly and accurately" (p. 146).

Table 7 Comparison of preservice biology teachers' and philosophers' conceptions about models

Preservice biology teachers' conceptions of models		Philosophers' conceptions of models	
		(Partly) similar conceptions	Additional conceptions
Models are tentative	Degree of simplification	Limited accuracy	Predictive power; simplification; correctness of model is not necessary Isomorphism is not possible
	An exact true model would be reality	Limited accuracy Isomorphism is not possible	Indirect examination of the model fit
	Falsification of models	Changing a model	
	Application of models	Testing a model Direct examination of the model fit is not possible[a]	Consolidation: testing a model Indirect examination of the model fit
	Role of model builder	Similarity Role of model user	Consolidation: similarity Consolidation: role of model user
	Changes in nature cause model changes Insufficient understandability Missing fit to theories Theory-/law-based change of model	No correspondences between preservice biology teachers' conceptions and investigated literature of the philosophers	
Models are certain	Models explain	Model fulfills the function	Consolidation: model fulfills the function
	Models as enduring constructs	Changing a model[a]	Changing a model
	Mesocosm	Mesocosm Tool for perception	Truth is not achieved by visualization
	Dependency on context	Similarity	Indirect examination of the model fit
	Idealization	Limited accuracy	Testing a model Indirect examination of the model fit
	Conservatism	Role of model user[a] (Negative heuristics)	Role of model user
	Testing to prove models	Direct examination of the model fit is not possible[a]	Testing a model Indirect examination of the model fit

[a] Refers to an opposite understanding between the preservice teachers and philosophers

The third conception, *missing fit to theory*, is only evident within the preservice teachers' views. Bailer-Jones (2002) stated that theories always require specification by means of boundary conditions. These are typical for a specific empirical situation and have to be included in the theory. The theory, in the form of a model, becomes applicable to the empirical world. Hence, a model is directly derived from the theory (**application of models*) with intended shortcomings in order to use the model in scientific practice. This does not affect the question of tentativeness.

Finally, the proposition within the subcategory *law-/theory-based change of model* remains vague. As outlined above, the relationship between models and theories is important. Contrary to the subcategory *model-based change of theory*, the conception of a change in law or theory change, which implies the change of a model, stays quite vague.

Contrary to the philosophers' positions presented here, there are subcategories for the preservice teachers' that include the notion of models as being final. *Verification of models* and *models explain* can be seen as the counterparts for the subcategories *verification of theories* and *theories explain* (see above). As for theories, models can be used for explanation. Bailer-Jones stated that the agreement between a model and empirical data fades into the background when there is an optimal fulfillment of function, such as the explanatory function by the model (**model fulfills the function*). Both preservice teachers and Bailer-Jones highlighted the explanative function of models, but the former connected it with the certainty of models, while the latter emphasized the lack of importance of the validity of models in this context.

Within *models as enduring constructs*, it is anticipated, as for *falsification of models*, that a model can get falsified. Contrary to *falsification of models* and Bailer-Jones' **changing a model*, one preservice teacher assumed that the model continues to exist, and a new model will be constructed.

The subcategory *mesocosm* takes account of limitations due to the certainty of models, that is, the only models that are certain are those where the originals can be observed. There are some similarities between this subcategory and Vollmer's remarks. He differentiated between objects that are already within humans' direct perception and some that are not (**mesocosm*) but that can be transferred to mesocosm by models (**tool for perception*). The preservice teachers also differentiated between these two dimensions in reference to the status of models. In particular, models that are derived from a perceptible original or phenomena (e.g., a human heart) are seen as most stable. Vollmer referred in his work mostly to entities that are beyond the mesocosm and that are transferred by models or other devices to the mesocosm in order to make them visual (**tool for perception*). On the contrary, Vollmer did not mention tools, such as models, in order to make entities visible that are already within mesocosm (e.g., a human heart). Vollmer denied the view, which was inherent to the preservice teachers' conception, that something visible has to be necessarily true, and emphasized that something outside of mesocosm could be potentially true (**truth is not achieved by visualization*); a view that was, at least indirectly, neglected by the preservice teachers.

Similar to *mesocosm* in the subcategory *dependency on context*, there are some limitations related to the certainty of models. It is stated that models are not always certain but only under special conditions. This context dependency is also apparent in Giere's idea of **similarity*, which includes the importance of the context in which a model is used. However, Giere stressed that there cannot be any true and definite models; rather, the relationship between a model and the real world is one of similarity (**indirect examination of the model fit*).

The subcategory *idealization* is, in some ways, contrary to the subcategory *degree of simplification*, discussed above, since exceptional cases of the original or phenomenon (e.g., "pathologically changed [hearts]", Marie; Table 3) are omitted in the model, and the real world entities (the hearts) are simplified in order to create an idealized version. This is similar to the philosophers' conception of the **limited accuracy* of models. However, within the subcategory, an evaluation of the idealized model (Bailer-Jones: **testing a model*; Giere: **indirect examination of the model fit*) is not included, and the idealization itself seem to be sufficient for the acceptance of a model.

Within the subcategory *conservatism*, a remarkable role is ascribed to the researchers, who constructed the model. It differs from Bailer-Jones' **role of model user*, where the model constructors' role is also highlighted. With a view to the assertions made by the interviewees (one example: see Table 3), it seems as if they attributed some sort of stubbornness to researchers, similar to what Lakatos described as **negative heuristics* for the continued existence of the hard core of research programs. A comparison can be drawn to what Kuhn (1962/2012) explained as "mop-up work", which is an attempt by scientists "to force nature into the preformed and relatively inflexible box that the paradigm supplies. [Phenomena] that will not fit the box are often not seen at all. [Scientists] are often intolerant of [theories] invented by others" (p. 24). Based on the history of science, Chinn and Brewer (1998) listed seven reactions that scientists show when they are confronted with anomalous data: ignore the anomalous data, reject the data, exclude the data from the domain of theory A, hold the data in abeyance, reinterpret the data while retaining theory A, reinterpret the data and make peripheral changes to theory A, and accept the data and change theory A, possibly in favor of theory B. Except for the latter two reactions, the other reactions correspond with the "mop-up work" that Kuhn described as well as the preservice teachers' conception of *conservatism*.

Finally, the subcategory *testing to prove models* includes the idea of a model being tested in such ways that one can assume the model has reached a final status. It neglects the view that a model cannot be true or false in respect to Giere and cannot be judged directly. Only predictions (Giere) or propositions (Bailer-Jones) derived from the model can be true or false. However, the statements made by the interviewees remained superficial, and further statements would be necessary to discuss the conception.

Implications for Teacher Education: Educational Guidelines

In order to connect teacher education with the analysis of preservice teachers' conceptions, we suggest that the different meanings of the terms delineated by different sources should be taught on the one hand, and on the other hand, that an understanding of which processes lead to the generation, evaluation, and refinement or rejection of theories and models should be discussed with preservice teachers.

Theories

This study revealed that preservice teachers often confused the term theory or degraded its importance within science. A lack of knowledge about what can be considered a scientific theory has been reported in many studies (cf. Lederman and Lederman 2014). However, it is noteworthy that even within science philosophy, different conceptions exist about what a theory is and what status a theory has. Hoyningen-Huene (2013) stated that even speculations can be theories (as long as they have a high degree of systematicity), while speculations within the Enzyklopädie Philosophie (Nuzzo 1999) are classified as everyday theories and stand in sharp contrast to scientific theories. Popper (1934/1971) distinguished between scientific theories and non-scientific theories on the basis of falsifiability. For teaching and learning situations, it needs to be considered that a wide variety of characteristics and definitions for scientific theories might confuse learners. Nevertheless, we suggest the value of highlighting that there are different perspectives about what constitutes a scientific theory. In particular, within NOS, it is not necessary to only teach one perspective about NOS aspects. New philosophical considerations can be fruitful in teaching and learning situations. As van Dijk (2013) states, Hoyningen-Huene "presents a thought-provoking image of science that is very useful for the debate on the nature of science within science education" (p. 2373). It is, therefore, recommended that teacher educators focus on this rather recent approach and compare it to other approaches in order to foster preservice teachers to develop a more comprehensive view of NOS. Only presenting a one-sided view on NOS may "lead to serious misunderstandings" (van Dijk 2013, p. 2372) about this controversially discussed topic.

In reference to the generation and evaluation of the theory described by the interviewees, two remarks have to be made. Firstly, although the understanding of the method of observation is not the focus of this article, it is necessary to enhance preservice teachers' understanding about observations as a valuable scientific method alongside experimentation (McComas 2002), since observations were seen as the basis for theories by some of the interviewees. Secondly, the principle of falsification by Popper was often named or referenced in the interviews. This can be used as a starting point not only to teach more in-depth knowledge but also to critique Popper's views, especially concerning the role of scientists. The latter is already included in traditional NOS views (see above). These refer to the personal background of scientists and their creativity and imagination as well as the cultural and social embedding of science (Lederman and Lederman 2014). In addition, Lakatos' approach should be seen as an additional perspective since scientists' roles within scientific theorizing are highlighted and, therefore, a contrasting view to Popper, who neglected the role of scientists and their intentional behavior, is presented.

Models

Interviewees often described the term model by its function of representing something (in a simplified way) and sometimes connected this to the tentativeness of models. This is in line with results of other studies: "biology teachers expressed mainly a limited understanding of models as copies or idealized depictions to show or to explain something" (e.g., Krell and Krüger 2016, p. 169). We suggest using this as a starting point and explaining the term model by the function a model can have. Following Hoyningen-Huene's differentiation between model and representation (see above), we suggest clarifying the terms in this manner and connecting them with their purpose (model: making predictions; representation: showing something in a systematized way). Hence, we recommend avoiding the word model in the context of showing or representing some sort of knowledge to learners. The differentiation between the application of a model (model *for* something) and the creation of a model (model *of* something; Mahr 2012) needs to be highlighted. Furthermore, the interviewed preservice teachers already saw models as simplified entities. However, it needs to be clarified that this characteristic does not negatively affect the function of a model to predict something. For many reasons (e.g., due to the model users' intention; Bailer-Jones 2009), it is not necessary to achieve a one-to-one correspondence between a model and real world in order to draw valuable predictions.

Even though the testing of a model was included in some conceptions, the direct testing of the model was assumed. Therefore, it needs to be highlighted that a judgment about the fit between a model and the real world has to take place. It needs to be emphasized that this can only happen in an indirect manner; direct testing of the model is not possible. Giere et al. (2006) provided a stepwise program to evaluate reports of scientific findings involving theoretical models, which they suggest can be used as a basic theoretical framework in order to understand and evaluate a broad range of scientific cases (e.g., the double helix case). Within this program, ideas are included regarding how the results of the comparison between data and model predictions should be judged. In order to connect to preservice teachers' conceptions, examples from the field of biology should be used to illustrate the philosophically-based positions and make them accessible. The interviews showed that preservice teachers who held conceptions close to the semantic or model-based view (Bailer-Jones; Giere) applied their conceptions to some extent to concrete biological models (*model-based change of theory*). Therefore, we recommend including concrete examples to familiarize learners with philosophical conceptions. In this context, explicit reflections on NOS aspects, including cases of the history of science, are valued as effective approaches (Clough 2011).

A few conceptions of the preservice teachers referred to a relationship between theories and models. There are many descriptions in historical and contemporary literature about theories and their status in comparison to other knowledge forms, such as models or laws, and vice versa. For example, Giere (2004) gave the following suggestion for theories:

> In my picture of scientific theories, there is no element explicitly designated as being "The Theory" or as being "A Law." This is because the terms "theory" and "law" are used quite broadly both in scientific practice and in metalevel discussions about the sciences. Their use typically fails to distinguish elements that I think should be distinguished if one is to have a sound metaunderstanding of scientific practice. (p. 746)

Nevertheless, Giere admits that it is "obviously desirable to follow widely accepted usage as much as possible" (p. 746), and, therefore, he rejects the word theory for his own account (instead he uses the term "principle") but does not demand a general shift in language use. Bailer-Jones (2004) highlighted the role of models in scientific practice and contemporary philosophy of science as such: Models describe the empirical reality and not theories. In particular, models have a mediating role between theories and the real world. Theories are seen as the depictions of general principles such as laws of nature and are only applicable on principle (i.e., global application). Models, in contrast, are developed and used to deploy and adapt the theory to a specific phenomenon (i.e., local application).

It becomes obvious that within science philosophy, a shift from theories to models has taken place, which should also be transferred to educational contexts, that is, highlighting the role of models first and foremost, with connections to theories.

Limitations of the Study

It is remarkable that some of the interviewees made contradictory statements during their interview. For example, Leon stated at the beginning of his interview that theories are "verified hypotheses [and] proven" (subcategory: *verification of theories*; Table 2). At a later point in the interview, he claimed that a theory needs to be changed if there are new research methods that reveal new observations, which are not in accordance with the theory (subcategory: *falsification of theories*; Table 2). Gropengießer (2001) stressed the existence of so-called Parakonzepte (para-conceptions), which are contradictory conceptions about the same sphere of reality and are often not recognized by interviewees. Additionally, the impact of the interview situation can cause the subjects to change conceptions about the respective topic. Therefore, the interview itself can be seen as one form of intervention in preservice teachers' conceptions.

In order to detect such para-conceptions and changes of conceptions, it would be necessary to analyze the single cases (cf. Schmidt 2010). Proceeding in this way, each person who participated in the study would have to be analyzed in terms of their individual views about the nature of theories and models.

The present study does not raise a claim of completeness concerning the theoretical saturation of the conceptions. That is, in further interviews, more reasons for the tentativeness or certainty of theories and models might be expressed. This is in line with Tracy's (2013) statement that "formal generalizations […] are […] ill suited for qualitative research" (p. 230). However, she listed other criteria that should be fulfilled within qualitative work in order to evaluate the trustworthiness of data. In this context it is not the volume of data, but the "density" of data that plays an important role, that is, the level of detail with which the data are analyzed. Here, the focus was not on the decision whether theories or models are tentative or not but on the reasoning of the preservice teachers.

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