Science & Education (2023) 32:1583–1611
https://doi.org/10.1007/s11191-023-00444-5

Check for updates

Evaluation of Nature of Science Representations in Biology School Textbooks Based on a Differentiated Family Resemblance Approach

Kristina Fricke[1] · Bianca Reinisch[1]

Accepted: 27 April 2023 / Published online: 7 June 2023

Abstract
Studies on the quality of nature of science (NOS) representations in school science textbooks report them being mostly of implicit manner and not fully adequate. However, the often underlying NOS framework of the consensus list in these studies is criticized as undifferentiated and inadequate. The family resemblance approach (FRA) to NOS shows potential to give differentiated insights into the appropriateness of NOS representations with avoidance of specifying certain philosophical directions. Based on a fine-grained differentiated FRA category system (11 main categories, e.g., "knowledge"; 52 subcategories, e.g., "hypotheses"), the quality of cognitive-epistemic NOS representations identified in seven biology school textbooks from Germany was analyzed. For this, a category system was developed. Cognitive-epistemic NOS representations in four chapters of each of the seven textbooks were evaluated regarding manner (implicit, explicit) and adequacy (adequate, (partly) not adequate). Results indicate, among others, that explicit representations of the cognitive-epistemic system of science were mainly placed in the introduction chapters, whereas subject-related chapters include mostly implicit representations. In this article, we present the evaluation of the quality of cognitive-epistemic NOS representations and discuss implications for science education.

Keywords Biology · Family resemblance approach · Nature of science · Textbooks

1 Introduction

Fostering an adequate understanding of nature of science (NOS) through science education aims at promoting students' scientific literacy (Lederman & Lederman, 2014). This is coherent with educational goals such as stated in normative standards (e.g., KMK, 2020; NGSS Lead States, 2013). In the growing body of science education literature addressing NOS, questions of *why* NOS should be included in science class are discussed, which come along with questioning *what* NOS aspects should be addressed

✉ Kristina Fricke
k.fricke@fu-berlin.de

1 Freie Universität Berlin, Schwendenerstr. 1, 14195 Berlin, Germany

(e.g., Erduran, 2022; Leden et al., 2020). In these studies, different levels of curricula are addressed (e.g., normative standards, e.g., Park et al., 2020a, 2020b; school science textbooks, e.g., McDonald, 2017; Park et al., 2020a, 2020b; Wei et al., 2021). Such studies often focus on selected NOS aspects (e.g., the diversity of methods; Wei et al., 2021), or on certain textbook elements (e.g., tasks; Park et al., 2020a, 2020b). They show, among others, NOS representations often being of implicit manner (e.g., McDonald, 2017) and a greater emphasis on cognitive-epistemic NOS aspects compared to social-institutional NOS aspects (e.g., Park et al., 2020a, 2020b). The results of such studies promote each other, considering that the *what* and *how* questions are deeply related (Erduran, 2022; Leden et al., 2020).

Compared with other NOS models such as the consensus view (Lederman & Lederman, 2014), the family resemblance approach (FRA) to NOS (Erduran & Dagher, 2014; Irzik & Nola, 2011) is a rather recent NOS model, which addresses the question of *what* NOS content should be addressed in science education. By adapting the FRA to NOS in science education, Erduran and Dagher (2014) provide approaches regarding both *what* and *how* NOS content should be addressed in school science. In the FRA, 11 NOS categories are differentiated into the cognitive-epistemic and the social-institutional system of science. For example, the category "Knowledge" as part of the cognitive-epistemic system describes "various forms of knowledge such as theories, laws and models emphasizing their coherence and contribution to the growth of scientific knowledge" (Erduran & Dagher, 2014, p. 113). Advantages of the FRA are grounded in its broad and expandable structure as well as in the interconnectedness of its categories, which makes it possible to highlight certain features of NOS on the one hand, and specificities of different scientific disciplines on the other hand (Reinisch & Fricke, 2022; Erduran & Dagher, 2014; Park et al., 2020a, 2020b). The utility of the FRA to NOS as a research tool in different domains of science education research is shown by the growing body of FRA-based studies, which are aiming at the identification, analysis, evaluation, and assessment of NOS views, NOS knowledge, or NOS representations in the written curriculum (i.e., instructional material such as normative standards and textbooks; Reinisch & Fricke, 2022; McDonald, 2017; Mork et al., 2022; Park et al., 2020a, 2020b; Park et al., 2020a, 2020b). Textbooks are orientated towards normative standards (*intended curriculum*; Valverde et al., 2002; e.g., KMK, 2020; NGSS Lead States, 2013) , and are used to direct strategies and practices taking place, for example, in the classroom (*implemented curriculum*; Valverde et al., 2002). Hence, textbooks are part of the *potentially implemented curriculum* (ibid.). As they "significantly shape the nature of classroom interactions" (Remillard & Heck, 2014, p. 713), their essential role in the process of the concretization of normative requirements in terms of the design of teaching and learning approaches is revealed. Analyzing the quality of textbook elements (e.g., text elements, figures, tables, tasks) addressing NOS aspects informs about *what* and *how* NOS is potentially taught.

The aim of our study is to analyze the quality of NOS representations in biology school textbooks from Germany to identify potentials to be used for the further development of instructional materials. Ultimately, the questions of *what* and *how* NOS content need to be introduced in the biology curriculum are addressed. For this, we investigate the manner and adequacy (*how*-question) of NOS representations in school biology textbooks presenting cognitive-epistemic FRA categories (*what*-question; Reinisch & Fricke, 2022). By means of this study, we aim to explore a more precise understanding of *what* specific NOS content can be fruitfully introduced when addressing certain biological topics within the curriculum.

2 Theoretical Background

2.1 The Family Resemblance Approach to Nature of Science

Since decades, NOS is described by the consensus view for science education purposes (Lederman & Lederman, 2014; Lederman et al., 1992). Seven NOS tenets are typically described: (1) Scientific knowledge is tentative, (2) empirically based, (3) subjective, (4) culturally embedded, and (5) includes human imagination and creative components. Furthermore, differentiations (6) between observation and interpretation and (7) between theories and laws are addressed. However, it is reported that the consensus view lacks certain NOS aspects such as the significance of models as form of scientific knowledge (Irzik & Nola, 2011). Also, it includes tenets which disregard the specificities of certain scientific disciplines (Schizas et al., 2016). For example, regarding forms of scientific knowledge, the significance of laws in contrast to rules in biology is described (Reutlinger et al., 2019; Rosenberg, 2008).

By adapting the FRA (Irzik & Nola, 2011) to NOS in science education (Erduran & Dagher, 2014), 11 NOS aspects are differentiated into the cognitive-epistemic and the social-institutional system of science. For example, scientific knowledge as a cognitive-epistemic category describes "various forms of knowledge such as theories, laws and models emphasizing their coherence and contribution to the growth of scientific knowledge" (Erduran & Dagher, 2014, p. 113). With its broad and expandable structure, the FRA to NOS (Erduran & Dagher, 2014) faces the criticism on other NOS conceptualizations such as the consensus view (Lederman & Lederman, 2014), on which it is also reported that it is not fully philosophically adequate (e.g., Erduran, 2014; Kaya & Erduran, 2016; Schizas et al., 2016; Van Dijk, 2011). An advantage of using the FRA as an analytical tool is the opportunity to describe NOS aspects without prescribing certain philosophical accounts such as logical positivism (i.e., knowledge is seen as limited to the interpretation of perceptible and verifiable findings; see Reinisch & Fricke, 2022 and Erduran, 2014). Erduran (2014) compared some key tenets of logical positivism such as the dichotomy of objectivity and subjectivity, and knower-knowledge and observer-observed dichotomies with NOS tenets of the consensus view (i.e., subjectivity and objectivity in science, creativity, and rationality in science). Erduran (2014) argues that "numerous examples […] put into question the logical positivist accounts of objectivity in science" (p. 97). The FRA counters the criticism facing dichotomous classifications such as of objectivity and subjectivity in science and the accompanying separation of scientific facts from interpretation. Within the FRA, objectivity is described as a cognitive-epistemic aim and value (Erduran & Dagher, 2014), which enables the recognition that scientifically gained knowledge is also underlying subjective influences:

> This approach […] is neutral in the sense that we do not have to choose between stereotypes of science, such as the views that science is subjective or objective. This approach enables us to show which aspects of science might support different views of what science is without the need to commit ourselves to any view. (Van Dijk, 2011, p. 1095)

2.2 The Question of *What*—The Differentiated Family Resemblance Approach

The following study is greatly based on the FRA to NOS (Erduran & Dagher, 2014) and on a previous study by the authors. For better understanding, we will outline this study (Reinisch & Fricke, 2022) in the following with a focus on the cognitive-epistemic system of science: To explore the broad variety of NOS aspects within the biology curriculum, we modified the FRA in the aforenamed study by further differentiating the initial 11 FRA categories (Erduran & Dagher, 2014) based on seven biology secondary school textbooks from Germany (Reinisch & Fricke, 2022). By means of a qualitative content analysis (Mayring, 2014), we inductively constructed subcategories based on the textbook material. For this, the textbook elements of four chapters (Introduction, Cell Biology, Genetics, Evolution Biology) within all textbooks were assigned to the 11 FRA-categories. Subsequently, all the codings (i.e., textbook elements assigned to FRA categories) in each of the 11 categories were collectively examined and subcategories were formed. Overlaps between the FRA-categories were qualitatively analyzed by differentiating theoretical justified overlaps (i.e., overlaps that are due to the content-related connection of respective subcategories) and overlaps which are due to lacking discriminatory power of the subcategories (Spendrin, 2019). This led to a modification of some of them (e.g., the cognitive-epistemic categories of "Methods" and "Methodological Rules" have been split; Reinisch & Fricke, 2022). The full process included several discussions between the involved and other researchers in biology and biology education. In sum, 29 distinct subcategories of the cognitive-epistemic system of science are described (Table 1). The relevance of the subcategories was also justified by referring to theoretical literature (e.g., Erduran & Dagher, 2014; Irzik & Nola, 2011).

By means of the subcategories (Table 1), the question of *what* NOS content is represented in school science is addressed. The subcategories of the differentiated FRA (Reinisch & Fricke, 2022) refer to NOS aspects which are assumed to include specificities of biology (as compared to physics or chemistry) and perhaps even of different disciplines of biology such as cell biology or evolutionary biology. For example, by use of the differentiated FRA, models and rules were discussed as distinct forms of scientific knowledge relevant for the field of biology and represented in school biology textbooks (Reinisch & Fricke, 2022). We assume that a further investigation of *how* these NOS aspects are represented in different contexts (i.e., different chapters of the textbooks such as cell biology or genetics) might be useful for the future design of NOS instructions. By use of the differentiated FRA for an analysis of the quality of NOS representations, we aim to depict their extent across different chapters and hence different contexts, which appears to be a fruitful approach in regard to analyzing NOS textbook representations in a fine-grained way (Reinisch & Fricke, 2022).

2.3 The Question of *How*—Empirical Studies on NOS Textbook Representations

In the science education research literature, there are textbook studies focusing on the analysis of selected NOS aspects (e.g., the diversity of methods; Wei et al., 2021), and studies focusing on certain textbook elements (e.g., tasks; Park et al., 2020a, 2020b; Park et al., 2020a, 2020b). In such studies, the questions of *what* and *how* NOS content is represented within the curriculum are addressed. Wei et al. (2021) derived a framework from Brandon's matrix including four categories of scientific methods to analyze representations of the diversity of methods in biology, chemistry, and physics school textbooks from China. They found that scientific methods are unevenly distributed along the four categories and provide implications for the representation of practical work in science textbooks. Park et al., (2020a, 2020b) analyzed 84 NOS tasks included in textbooks for the Korean school subject "scientific inquiry and experimentation" by an inductive approach. The authors found that school science textbooks often include multiple NOS aspects, which mostly address historical contexts, but lack proper cues for reflections. It is worth noting that science education research has suggested that NOS teaching along different contexts can be effective for fostering adequate NOS understanding. Bell et al. (2016) examined effects

Table 1 The categories of the cognitive-epistemic system and evidence found from the analysis of seven biology school textbooks (Reinisch & Fricke, 2022)

(Sub)category	Description	Evidence from the textbooks ($N=7$)
Aims and Values	Scientific research is guided by cognitive-epistemic aims and values concerning …	
Objectivity	… objectivity: It is named or described that science aims to gain objectively achieved knowledge	Science enhances knowledge by gaining objective data, […] (C-SII, p. 14)
Testability	… testability: It is named or described that scientific statements must be testable including to be falsifiable and/ or verifiable	From the fact that science is concerned with testable statements, it does not follow that there are only scientifically testable matters in the world. (W-SII-L, p. 551)
Novelty	… novelty: It is named or described that science is searching for new explanations	Until the middle of the nineteenth century, it was not known how characteristics are inherited. Only through many experiments by the monk Mendel were the so far unknown regularities of heredity successfully proven. (C-SI, p. 256)
Criticism	… alternative ideas: It is named or described that science can lead to opposite ideas or that science seeks and values criticism or responds to objections	It is understandable that the spectacular fossil finding led to severe disputes between proponents and opponents of the evolutionary theory very soon after its discovery. (C-SII, p. 274)
Empirical Adequacy	… empirical adequacy: It is named or described that science is basing claims on sufficient, relevant, and plausible data	At least one second big wave of emigration, which is dated in the time period of 800,000 to 1 million years ago, has been confirmed: populations arrived in Asia but also in Europe. (C-SII, p. 286)
Scientific Practices		
Practices	Natural objects, processes, and systems are …	
Observing	… observed: Characteristics of observations are named, e.g., observation include fossil finds; observations conducted by scientists are named or described; students are asked to observe	Observation is grasping objects or processes with the senses without influencing them. (C-SII, p. 14)

Table 1 (continued)

(Sub)category	Description	Evidence from the textbooks ($N=7$)
Experimenting	… investigated experimentally: Characteristics of experiments are named, e.g., in an experiment one intervenes in the function of an object, a process, or a system; experiments and investigations with experimental characteristics conducted by scientists are named or described; students are asked to experiment	Scientific experiment. Also, in a scientific experiment data are generated, interpreted, and discussed with the purpose of finding answers to a research question. In contrast to an observation, in an experiment one intervenes in the function of a biological system, for instance by pressing blood vessels to stop blood flow. (W-SII-L, p. 15)
Comparing and Classifying	… compared and classified: Characteristics of the methods comparison and / or classification are named; comparisons and / or classifications conducted by scientists are named or described; students are asked to compare and/ or classify	Classification in the natural system. If you want to classify a living being in the natural system, you have to analyze its similarity to other living things and find homologies as the cause of the similarity. […] (C-SII, p. 268)
Modeling	… investigated by use of models/ model organisms: Characteristics of the modeling process with or without using model organisms are named, e.g., by modeling one can represent an idea of the investigated object structure; modeling processes conducted by scientists are named or described; students are asked to model	They used data and findings from other scientists such as Rosalind Franklin (1920 – 1958) and derived the spatial structure of DNA with a model. (K- SII, p. 146)
Work Techniques	Natural objects, processes, and systems are observed, (experimentally) investigated, compared, classified, or investigated with the use of models/ model organisms with the aid of …	
Chemical and Physical Techniques	… chemical and physical techniques: Characteristics or the significance of the functional use of tools in chemical and physical techniques are named or described, e.g., using the microscope, the application of chemicals, physical measuring instruments, cultivating and culturing cells, gene transfer, DNA-chip-technologies, PCR; students are asked to conduct or reflect chemical and physical techniques	Recombinant DNA can be converted into gene products only if it gets into the host cell. Commonly, vectors with specific characteristics are used for the transmission. Vectors must be replicable, which means they have a sequence that functions as the origin of the replication. […] (C-SII, p. 188)

Table 1 (continued)

(Sub)category	Description	Evidence from the textbooks ($N=7$)
Mathematization	… mathematization: Characteristics or the significance of the functional use of tools in mathematical techniques are named or described, e.g., formalization, quantification; students are asked to conduct or reflect techniques of mathematization	He investigated more than 10,000 plants and incorporated the findings completely into the study, which means he assessed them statistically. Such an approach was strange for biologists in his time. (C-SII, p. 164)
Preparation	… providing research objects: Characteristics of the functional application of techniques with the aim of preparing examination material are named, e.g., procedures concerning excavation works; students are asked to extract research objects	Many of the work steps are not taking place at the excavation site but in the laboratory. Here, findings have to be cleaned and extracted from remaining rocks. (K-SI, p. 130)
Documentation	Results or methodical steps are documented by …	
Protocolling	… texts and tables: Protocolling as a form of documentation is named or described; students are asked to prepare a protocol	"I collected 46 pieces from 39 species on Tuesday; 37 pieces from 33 species on Wednesday, of which 27 were different from the ones of the previous day." Henry W. Bates wrote in his diary in 1848. (C-SII, p. 238)
Drawing	… sketches and drawings: Drawing as a form of documentation is named or described; students are asked to make a drawing	Hooke captured all his observations in the form of drawings and sketches. (C-SII, p. 19)
Taking Photographs	… photographs: Taking photographs as a form of documentation is named or described; students are asked to take a photograph	If possible, take a photo of your preparation and produce a karyogram by using it. (C-SII, p. 28)
Constructing Diagrams	… diagrams, e.g., crossbreed schemata or genealogy trees: Constructing diagrams as a form of documentation is named or described; students are asked to construct a diagram	The results of the sequencing process can get presented in a 'genealogical tree of cytochrome c.' Here, the lengths of the lines between two species are communicating how similar the sequences of amino acids of the two species are – the shorter the distance, the more similar the sequences. (W-SII-L, p. 526)

Table 1 (continued)

(Sub)category	Description	Evidence from the textbooks ($N = 7$)
Reasoning	The scientific path of acquiring knowledge entails different lines of thinking implemented in forms of scientific reasoning. Knowledge is gained …	
Scientific approaches		
Hypothetical-deductive Approach	… by the hypothetical-deductive approach: It is named or described that scientific inquiry is guided by a procedure, which goes from a research question over to generating a deductive hypothesis culminating in the conduction of a certain practice revealing data, which are analyzed and discussed in the aim of falsifying or supporting the initial hypothesis	Figure including the following steps: Research question → Generating a hypothesis → Planning an experiment to verify the hypothesis → Conducting the experiment → Describing the data → Discussion: Was the hypothesis falsified or supported? (W-SII-L "Acquiring knowledge by experimenting", p. 14)
Forms of reasoning		
Inductive Reasoning	… inductively: It is named or described that general knowledge is obtained from the abstraction of single findings; students are asked to reason inductively	From the observation of cell divisions, [Rudolf Virchow] concluded that all cells arise only from existing cells: Omnis cellula e cellula. (C-SII, p. 19)
Deductive Reasoning	… deductively: It is named or described that single findings are predicted by considering well-known cases and hence, general knowledge; students are asked to reason deductively	*Task*: Explain which consequences would emerge if the reduction division during the production of gametes would not take place. (C-II, p. 267)
Abductive Reasoning	… abductively: It is named or described that reasons for an observation are given by considering prior knowledge and hence, inferring a coherent causal conclusion on the certain case; students are asked to reason abductively	Mendel already assumed that self-pollination and autogamy, processes that are common for pea plants, cause the level of homozygosity. (C-SII, p. 164)
Methodological Rules	In scientific practices, scientists follow the methodological rules, so that …	
Rejection or Change of Theoretical Constructs	… theoretical constructs are rejected or changed: It is named or described that scientific constructs such as hypotheses, theories, or models are being rejected or changed, e.g., because of new findings	Therefore, it is understandable that statements about the course of the phylogeny contain some uncertainty and must be repeatedly modified or even revised due to new findings. (C-SII, p. 290)

Table 1 (continued)

(Sub)category	Description	Evidence from the textbooks ($N=7$)
Conduction of Controls	… controls are conducted: It is named or described that, when applying one of the scientific practices (e.g., observing, experimenting), controls need to be considered, e.g., repetitions or control groups	Task: […] Repeat the process for each catalase concentration at least three times. (K-SII, p. 69)
Choice of Sample Size	… an appropriate sample size is chosen: It is named or described that, considering statistical analyses, scientific research needs to be based on a big sample size	Task: Justify why a large number of individuals had to be counted to secure the results (C-SI, p. 261) Answer: In statistical measurements, the more single results you have, the more exact your final result will be. (C-SI solutions, p. 104)
Choice of Research Object	… an appropriate research object is chosen: It is named or described that, considering a specific research question, the research object must show relevant characteristics (e.g., durability, variability) or fulfill corresponding criteria (e.g., expenses)	Osmosis and plasmolysis are investigated well on plant tissue, because it has stable cell walls. (C-SII, p. 50)
Avoidance of Ad-hoc Changes in Theoretical Constructs	… ad-hoc changes in theoretical constructs are avoided: It is named or described that, considering the explanatory potential of theoretical constructs, they must not be changed because of new evidence if it is still justified by other evidence	Despite all difficulties in individual cases [regarding the ambiguity of findings], the fundamentals of human fossil history are uncontroversial. (C-SII, p. 290)
Scientific Knowledge	Scientific knowledge as a product of the scientific enterprise highlighting their contribution to their growth is represented in …	
Hypotheses	… hypotheses: The term “hypothesis” is defined, functions and characteristics of hypotheses are named	A scientific hypothesis is a justified assumption, which stands in line with scientific knowledge and represents a possible answer for a research question. A hypothesis must be formulated without internal contradictions and must be testable. (W-SII-L, p. 14–15)

Table 1 (continued)

(Sub)category	Description	Evidence from the textbooks ($N = 7$)
Theories	… theories: The term "theory" is defined; functions and characteristics of theories are named	Even a theory—a system of scientifically justified, self-consistent statements for the description, explanation, and prediction of reality—always remains preliminary knowledge. No theory can be "proved" by new findings, but only supported, questioned or refuted. (C-SII, p. 14)
Models	… models: The term "model" is defined; functions and characteristics of models are named	Every scientific model represents an approximation to reality. It attempts to explain as many observations and known facts as possible. It also allows for predictions that guide further research. New findings often make it necessary to develop a valid model or even replace it with a new one. (C-SII, p. 46)
Rules	… rules: The term "rule" is defined; functions and characteristics of rules are named	Often characteristics of phylogenetic ancestors appear in the early individual development of organisms in a similar form. This fact is outlined simplified by the biogenetic rule […] (W-SII-L, p. 503)

The abbreviations of the textbook sources (e.g., C-SII) are outlined in chapter 4.1; bold: main categories, italics: organization of subcategories; the original statements were translated by the authors from German into English and may therefore differ slightly from the original syntax of NOS instruction on the development of prospective teachers' NOS conceptions along a continuum of science content. Their findings suggest that teaching NOS lessons along a contextual continuum can be effective in promoting prospective teachers' adequate understanding of NOS concepts and corresponding instructional intentions.

For analyzing the quality of textbooks regarding NOS representations, the criteria of *manner* (explicit or implicit representation of NOS aspects), *adequacy* (naïve or adequate representation of NOS aspects), *consistency* (consistent or inconsistent representation of NOS aspects throughout the textbook), and *completeness* (complete or incomplete representation of NOS aspects) are often considered (e.g., Abd-El-Khalick et al., 2008; McDonald, 2017; Park et al., 2020a, 2020b; Zhuang et al., 2021). In the following, the meanings of the criteria are shortly outlined. The criteria correspond to the target NOS statement (e.g., characteristics of theories) and are applied without considering possible subject-related contexts (e.g., content of the endosymbiotic theory; Abd-El-Khalick et al., 2008). Explicit NOS representations directly address certain NOS statements and can include opportunities for reflection. In contrast, implicit representations include statements from which the target NOS statement must be derived, which requires a certain level of interpretation performance (Abd-El-Khalick et al., 2008; Scharmann et al., 2005). Both explicit and implicit representations can address NOS statements on an abstract level (i.e., decontextualized statements, e.g., addressing scientific research on a meta-level) and on a concrete level (i.e., contextualized statements, e.g., historical case examples illustrating scientific research; see Abd-El-Khalick et al., 2008; Scharmann et al., 2005). It has largely been discussed that "an explicit and reflective inquiry-based approach is more effective" for students to build up an adequate NOS understanding compared to implicit approaches (Abd-El-Khalick & Akerson, 2004; Khishfe & Abd-El-Khalick, 2002; Koksal et al., 2013; Leden et al., 2020). Following this, school textbooks should explicitly portray NOS aspects and further include reflective elements to foster an adequate students' NOS understanding (Erduran et al., 2019).

The scoring rubric by Abd-El-Khalick and colleagues (2008) has been proven useful and valid for evaluating NOS textbook representations addressing the NOS tenets of the consensus view (Abd-El-Khalick et al., 2008, 2017; Ramnarain & Chanetsa, 2016; Zhuang et al., 2021). Considering the criteria of *manner* (explicit, implicit), *adequacy* (naïve, informed), *consistency* (given, not given), and *completeness* (given, not given) of NOS related material, textbooks are holistically analyzed. That is, textbooks are assigned to a score ranging from + 3 to − 3 depending on the characteristics of the four criteria. For example, a score of + 3 indicates the occurrence of "explicit, informed, and consistent representation of the target NOS aspect" (Abd-El-Khalick et al., 2008, p. 841). By the means of the tenet of "tentative NOS" (i.e., scientific knowledge is subject to change),

> textbook materials should explicitly convey the notion that all categories of scientific knowledge are subject to change. An example of the lack of *consistency* in this case would be stating that scientific theories are subject to change while emphasizing that scientific laws are 'facts' or 'truths'. (Abd-El-Khalick et al., 2008, p. 841)

At the opposite end of the scoring rubric, textbooks assigned to a score of − 3 indicates that it is rated as an "explicit statement or statements that clearly communicate a naïve representation of the target NOS aspect, such as, 'A scientific law is simply a fact of nature that is observed so often that it becomes accepted as truth' (Abd-El-Khalick et al., 2008, p. 842). Thus, a higher score represents that a textbook meets more of the selected criteria compared to other textbooks. With the division of the rubric into plus and minus ranges aligned to the criterion of *adequacy*, only sections rated as informed are in the plus range.

A score of 0 indicates that "the target NOS aspect is not addressed" (p. 842) The authors report on sufficient inter-rater reliability of the scoring rubric with a percentage agreement of 86% between two involved researchers. Regarding validity, the authors justify the use of the scoring rubric by theoretical grounding of the study (e.g., Abd-El-Khalick & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002). Thus, we assume that the quality with which textbooks or textbook sections address certain NOS aspects assigned to certain NOS tenets such as portrayed by the consensus view can be holistically assessed using the scoring rubric.

However, to derive tangible suggestions for the future design of instruction materials, an approach is required which primarily does not reveal the deficits of textbooks, but the potential of single, even implicit but contextualized representations (see Erduran & Dagher, 2014). We assume that a more detailed analysis of single NOS representations will give valuable insights into their quality and thus provide useful starting points for the (further) development of NOS instruction in science education.

Empirical studies on the extent and quality of NOS representations using the FRA as underlying framework show them being often implicitly and not fully adequately represented (e.g., BouJaoude et al., 2017; McDonald, 2017; Park et al., 2020a, 2020b; Park et al., 2020a, 2020b). For example, McDonald (2017) referred to Abd-El-Khalick et al. (2017) and analyzed the *manner* of NOS representations in biology school textbooks. The author deductively assigned textbook units to the categories explicit and implicit and found that most of the NOS representations are of implicit manner. This is in line with studies using alternative NOS frameworks such as the tenets of the consensus view (e.g., Abd-El-Khalick et al., 2008, 2017; Chua et al., 2019; Ramnarain & Chanetsa, 2016; Zhuang et al., 2021). However, by using a closed list of consensus NOS tenets, one can only provide insights into the quality of representations addressing these tenets. The FRA includes added values compared to such tenet's lists (i.e., its broadness, expandability, and the possibility of avoiding certain philosophical directions; Reinisch & Fricke, 2022; Erduran, 2014), which should be considered in science class (Erduran & Dagher, 2014; Erduran et al., 2019) . By analyzing NOS representations, which are identified by use of the differentiated FRA (Reinisch & Fricke, 2022), detailed insights into the portraiture of NOS can be provided. For example, by use of the FRA, representations of models as form of scientific knowledge were identified (Reinisch & Fricke, 2022). Regarding the introduction of NOS in science class, it is relevant to link the "what" question (differentiated FRA; Reinisch & Fricke, 2022) with the "how" aspects such as *manner* of NOS representations used in teaching.

3 Research Aim and Questions

This study aims to analyze the extent and quality of cognitive-epistemic NOS representations in German school biology textbooks for secondary level. This is explored through the following two research questions:

RQ 1: To what extent are cognitive-epistemic NOS representations *explicitly* portrayed?

It is reported that NOS textbook representations are mostly of implicit manner (e.g., Abd-El-Khalick et al., 2008, 2017; McDonald, 2017; Park et al., 2020a, 2020b). Thus, we expect that overall there is a greater number of implicit than explicit NOS representations in the school biology textbooks. We further expect that the introductory sections of the textbooks contain a greater number of explicit NOS representations compared to subject-related chapters (Abd-El-Khalick et al., 2008, 2017; McDonald, 2017). Nevertheless, we assume that implicit representations hold potential to enhance the quality of NOS instruction materials as they could serve as a basis for the development of explicit NOS representations. In this study, we focus on the qualitative analysis of single NOS representations, rather than of whole textbooks or textbook sections.

RQ 2: To what extent are cognitive-epistemic NOS representations *adequately* portrayed?

Studies showed that NOS textbook representations are often not adequately or only partly adequately represented (e.g., Abd-El-Khalick et al., 2008, 2017; McDonald, 2017; Park et al., 2020a, 2020b). Hence, we expect that school biology textbooks in Germany similarly include NOS representations, which are at least in parts not adequate.

As it was found that certain textbook chapters contain different NOS representations than others (e.g., Abd-El-Khalick et al., 2017; Chiappetta & Fillman, 2007), we assume that an evaluation of the extent and quality of such representations in different chapters leads to a detailed understanding of potential ways to contextualize them for science education purposes. Potential relations between certain FRA (sub-)categories (Reinisch & Fricke, 2022) and certain textbook chapters might point out which biology-related topics can primarily be used in the classroom to foster certain NOS aspects (Chua et al., 2019; Erduran et al., 2019). We thus aim to analyze the occurrence of NOS representations across different textbook chapters.

4 Methods

In a previous study (Reinisch & Fricke, 2022), seven biology school textbooks for secondary levels from Germany were qualitatively analyzed to evaluate and differentiate the FRA categories (Erduran & Dagher, 2014; Table 1). The present study builds on the results by further analyzing the same data.

4.1 Sample

The sample selection of this study corresponds to the sample selected by Reinisch & Fricke (2022) and was done in accordance with different criteria which are outlined in the following: (i) For a detailed qualitative text analysis, textbooks were chosen which were written in the mother language of the involved researchers. Thus, textbooks in German language were considered. (ii) Considering a possible author- and publisher-effect (i.e., the influence of authors and publishers on the integration of content into textbooks; Abd-El-Khalick et al., 2008, 2017; DiGiuseppe, 2014), textbooks from different groups of authors and publishers were chosen. (iii) Considering different levels of secondary education, school textbooks from different levels of secondary education (grades 7–10, grades 10–13) were chosen. (iv) Regarding a possible extension of the overall research project, the potential influence of textbooks on students' NOS understanding (Bou-Jaoude et al., 2017; Remillard & Heck, 2014) was also considered. For this purpose, textbooks were selected, which are assumed to be used in the classroom. Thus, the most sold titles of the three largest school textbook publishers in Germany were considered.

Additionally, 60 biology teachers who also work as teacher educators from 12 of the 16 federal states in Germany named in a questionnaire survey the biology school textbooks used in their schools. As a result, seven biology school textbooks were chosen.

Due to the high data volume to be considered in qualitative text analyses, partial analyses are typically performed (Abd-El-Khalick et al., 2017) . To test our expectation for RQ 2, textbook chapters were chosen based on research findings of similar textbooks studies on NOS representations: cell biology (Abd-El-Khalick et al., 2017; Chiappetta & Fillman, 2007; Wei et al., 2013), genetics (Abd-El-Khalick et al., 2017; Chiappetta & Fillman, 2007; Erduran, 2014; McDonald, 2017), and evolution (Abd-El-Khalick et al., 2017; Chaisri & Thathong, 2014; Chiappetta & Fillman, 2007; Erduran & Dagher, 2014; Wei et al., 2013). These chapters offer a wide range of potential NOS contexts and previous studies have already found increased NOS representations in similar topics (e.g., Abd-El-Khalick et al., 2017; Chaisri & Thathong, 2014; Chiappetta & Fillman, 2007; McDonald, 2017). Additionally, introductory chapters which include for example general scientific methods sections were considered (Abd-El-Khalick et al., 2017; Chiappetta & Fillman, 2007). In sum, the sample selection resulted in 1258 textbook pages taken from four chapters of each of the seven biology school textbooks (Table 2; Reinisch & Fricke, 2022).

4.2 Data Analysis

4.2.1 Preparation of Data

In the present study, we further analyze the NOS representations which were previously coded into the subcategories of the cognitive-epistemic system of science described by the differentiated FRA (Reinisch & Fricke, 2022). Reinisch & Fricke (2022) reported that reliability measurements revealed "almost perfect" ($\kappa = 0.95$) intra- and "substantial" inter-rater reliability ($\kappa = 0.80$; Landis & Koch, 1977, p. 165) in the category system.

To compare the quantitative data of single textbook units regarding the criteria of *manner* and *adequacy*, single textbook units were taken from the previous study (i.e., text elements, figures, tables, tasks; Reinisch & Fricke, 2022) and combined into larger NOS representations. A representation is defined as the sum of textbook material (i.e., the sum of text elements, figures, tables, tasks) that (i) address the same FRA subcategory (e.g., "Theories," Table 1; Reinisch & Fricke, 2022) and (ii) are identified as one unit of meaning (i.e., portrayed within the same section of a chapter). Following this, a representation is either a textbook unit as already coded by Reinisch & Fricke (2022) or the consolidation of several single former textbook units which together depict content of a NOS aspect and appear at a nearby place in the textbook (e.g., in a paragraph immediately following another paragraph). Figure 1 shows an example of the transformation of two textbook units addressing "Theories" (as coded by Reinisch & Fricke, 2022) into one representation. An example of a representation consisting of both text material and a table is presented in the results (see Section 5.3).

The transformation of textbook units (Reinisch & Fricke, 2022) revealed 2.908 representations of the cognitive-epistemic system of science to be analyzed in total. The transformation process was conducted in consultation between the two authors and a trained student assistant. All representations were implemented into the MAXQDA analysis software (VERBI Software, 2019).

Table 2 Sample

Publisher	Textbooks for secondary level I (grades 7–10)	No. of pages	Textbooks for secondary level II (grades 11–13)	No. of pages
Cornelsen	C-SI (Leienbach, 2016)	104	C-SII (Weber, 2016)	220
Klett	K-SI (Bickel et al., 2016)	113	K-SII (Bickel et al., 2020)	250
Westermann	W-SI (Hausfeld & Schulenberg, 2016)	119	W-SII-B (Bayrhuber et al., 2019a)	241
			W-SII-L (Braun et al., 2012)	211

The abbreviations of the textbooks are composed of the first letter of the corresponding publisher (*C* Cornelsen, *K* Klett, *W* Westermann), the type of secondary level (I/II), and in the cases of W-SII, the first letter of the respective textbook title

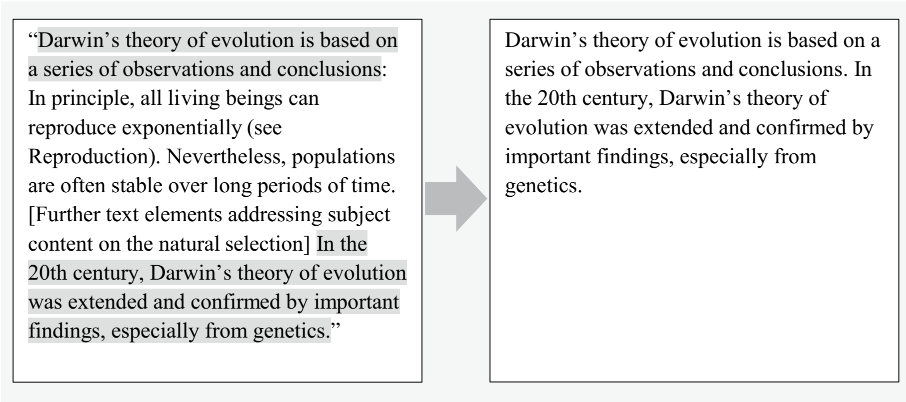

Fig. 1 Exemplary transformation of two textbook units addressing theories (grey highlighted text: as coded in Reinisch & Fricke, 2022; W-SII-B, Evolution, p. 363) in the context of the textbook (left side) into one representation to analyze in the present study (right side)

4.2.2 Qualitative Analysis

To investigate the quality of cognitive-epistemic NOS representations, a category system was developed. For this, the criteria of *manner* (categories: explicit, implicit) and *adequacy* (categories: given, not given) were deductively taken from the scoring rubric (Abd-El-Khalick et al., 2008). Although described as a valid and reliable instrument for evaluating NOS representations (e.g., Abd-El-Khalick et al., 2008; Chua et al., 2019), the specificities of the FRA to NOS as an underlying theoretical framework and the research aim of the present study (i.e., analyzing single representations instead of whole textbooks or textbook sections) were considered. In the following, such considerations are shortly highlighted.

In the initial rubric (Abd-El-Khalick et al., 2008), the criterion of *completeness* is defined as an integral part of *adequacy*. It is described that a "*partially informed* representation of the target NOS aspect [is due to the identification of] (i) explicit statements that convey an *informed, but incomplete* representation, and (ii) consistency across the selected chapters or sections in representing the target NOS aspect" (Abd-El-Khalick et al., 2008, p. 841). As the claim to *completeness* contradicts the idea of the expandability of FRA categories (Erduran & Dagher, 2014), the data were not analyzed according to this criterion. Furthermore, to assess claims regarding the *adequacy* of NOS representations, clearly defined levels of expectations (e.g., normative standards) are needed for both lower and higher secondary classes. However, it is reported that normative standards often include only few statements addressing NOS, that they are mostly of implicit manner, and that they are partly related to different disciplines (i.e., different subjects; Caramaschi et al., 2022). Since the coding unit was defined as one NOS representation (Fig. 1), *consistency* was evaluated alongside the criterion of *adequacy*. For example, both informed and naïve statements within one NOS representation are in sum rated as a (partly) not adequate representation.

In sum, the criteria of *manner* (categories: explicit, implicit) and *adequacy* (categories: given, not given; including *consistency*) were applied, which led to the development of a category system including four categories (Table 3). Several discussions with experts of biology education ($N=9$) accompanied this process.

To present the descriptions of the categories more clearly, fictitious examples are assigned to the categories below. To make the description of the categories more clear, in the following, fictive examples are assigned to the categories. An example for an adequate representation of explicit manner (Table 3: 1A) is the following statement: “The synthetic evolutionary theory is *proven*.” In this example, the target NOS statement “theories are to be proven” is directly addressed and must not be derived (Scharmann et al., 2005). In contrast, a statement such as “The synthetic evolutionary theory is *correct*.” would be rated as still explicit, but (party) not adequate (Table 3: 2A) as “correctness” is a misleading term regarding the tentativeness of scientific knowledge forms such as theories. An example for an adequate representation of implicit manner (Table 3: 1B) would be the following task: “Explain how the findings *support* the theory.” If this task does not explicitly show the connection between data and theory, it must be derived from the context. The target NOS statement “theories are to be proven” would then have to be derived by recognizing that research findings can be used to support theories. In contrast, a task formulated like “Explain the *correctness* of the theory about the phylogenetic origin of mitochondria in animal cells by referring to the findings” would be rated as still implicit, but (party) not adequate (Table 3: 2B). From this fictitious example, the statement that one can prove the *correctness* of a theory based on data can be derived. This does not do justice to the tentativeness of scientific knowledge and empirical adequacy in the context of theory development. Representations that only include statements, which are not assessable, were not considered (e.g., when the target NOS aspect is only referred to in summaries of the goals to be achieved at the end of a chapter).

The content validity of the category system (Table 3) results from both theoretical and empirical foundation. The differentiated FRA to NOS (Reinisch & Fricke, 2022) relies on the theoretical framework of NOS for science education described by Erduran and Dagher (2014). The dimensions of the target FRA categories (i.e., the FRA subcategories; Reinisch & Fricke, 2022; Table 1) are based on an empirical investigation of seven biology school textbooks from Germany in accordance with relevant literature related to the subcategories (e.g., Reutlinger et al., 2019 and Rosenberg, 2008 for the subcategory “Rules”) and discussions with experts from the field of science education research. The use of the criterion *manner* can be justified by studies cited above, which have shown that explicit NOS instructions are more effective in teaching than implicit approaches (e.g., Abd-El-Khalick & Akerson, 2004; Koksal et al., 2013; Scharmann et al., 2005). The use of the criterion

Table 3 Category system for evaluating the quality of NOS representations based on the FRA

Category	Explicit	Implicit
Adequate	(1A) The representation includes at least one explicit statement about the target NOS aspect. Explicit representations can include implicit ones. All statements are adequate	(1B) The representation includes at least one implicit statement about the target NOS aspect. No explicit statement is included. All statements are adequate
(Partly) not adequate	(2A) The representation includes at least one explicit statement about the target NOS aspect. Explicit representations can include implicit ones. Statements are (partly) not adequate	(2B) The representation includes at least one implicit statement about the target NOS aspect. No explicit statement is included. Statements are (partly) not adequate

adequacy can be justified by the assumption that (partly) not adequate representations can lead to both teachers' and students' misinterpretations and misunderstandings of the target FRA subcategory.

As a measure of reliability, a randomly selected 10% of the sample (Krüger & Riemeier, 2014) was independently coded by the two authors. The calculation of Cohen's kappa revealed "almost perfect" interrater-reliability ($\kappa = 0.83$; Landis & Koch, 1977, p. 165). The textbook units were compared and discussed until consensus was reached (Schreier, 2014). The first author then coded the rest of the material. On a selective basis, further NOS representations were given to the second author for an independent coding if the NOS representation could not be coded unambiguously by the first author.

4.2.3 Quantitative Analysis

Since it can be assumed that a greater number of pages will result in a greater number of NOS representations, their relative frequencies were calculated. To investigate the extent of explicit (RQ 1) and adequate (RQ 2) cognitive-epistemic NOS representations in relation to the volume of the total material, the average number of representations per page was calculated for each chapter. To compare the relative frequencies of the representations in the different chapters, group comparisons were conducted (Field, 2018). For this, differences between the introduction chapters and the subject-related chapters (i.e., Cell biology, Genetics, Evolution) were analyzed by applying the Mann–Whitney *U* test. To analyze differences between the five main FRA categories (Reinisch & Fricke, 2022) the Kruskal–Wallis test and the Mann–Whitney *U* test were applied. For the interpretation of the effect size measure, Cohen's *d*, Cohen's (1988) recommendation of small ($d > 0.2$), medium ($d > 0.5$), and large ($d > 0.8$) effects was applied (Fritz et al., 2012).

5 Results

5.1 Extent of NOS Representations—Overview

The analysis of 2.908 cognitive-epistemic NOS representations revealed differences in the frequency of representations across different FRA categories and chapters, which are described below.

The calculation of the average number of NOS representations per page revealed frequencies ranging from 1.3 (Genetics, W-SII-B; Evolution, W-SI) to 6.8 (Introduction, W-SII-B; Fig. 2). The median is at 2.3. Figure 1 shows the extent of representations addressing different FRA categories across the chapters. The FRA category "Scientific Practices" (Table 1) is most highlighted in the textbooks across the chapters (Fig. 2).

Some of the categories are addressed with varying frequency across the chapters. For example, representations of the category "Aims and Values" are included more frequently in the evolution chapters than in the chapters related to the subjects of cell biology and genetics (Fig. 2). Most of these representations address the subcategory of "Empirical Adequacy" (Table 1; Reinisch & Fricke, 2022). An example for such a representation in the evolution chapter is the following text element: "The upright gait can be directly proven by the construction of the pelvis, but also by footprints preserved in volcanic ash" (C-SII, Evolution, p. 285).

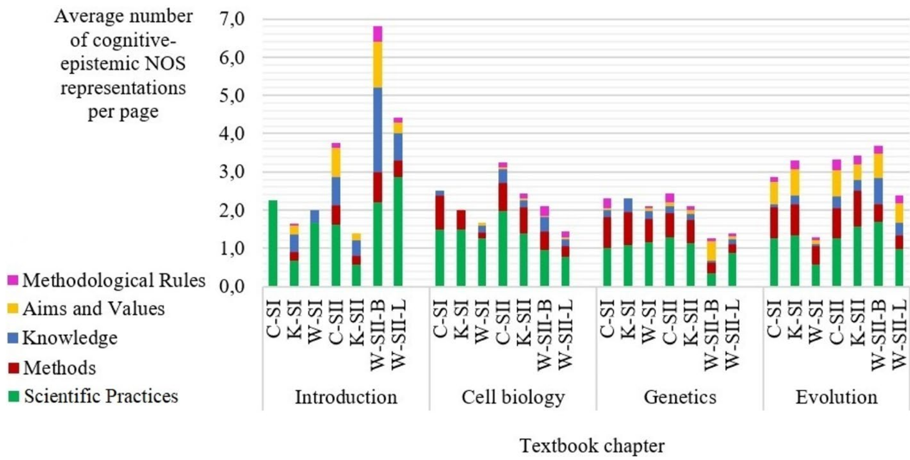

Fig. 2 Extent of NOS representations across the five main categories of the cognitive-epistemic system and different chapters in the seven biology school textbooks ($N_{pages(Introduction)}=70$, $N_{pages(Cell\ biology)}=226$, $N_{pages(Genetics)}=532$, $N_{pages(Evolution)}=410$)

5.2 Quality of NOS Representations—Overview

The analysis of cognitive-epistemic NOS representations revealed that the textbooks contain NOS representations of different *manner* and different levels of *adequacy*. Table 4 shows examples from the textbooks addressing the sub-category "Theories" (Table 1). In the following, the assignment of the examples to the categories of *manner* and *adequacy* is described.

In the explicit and adequate statement exemplarily presented in Table 4 (1A), the tentativeness of theories is directly addressed. Since the use of the term "proven" expresses that a theory has validity if it can be justified with empirically obtained data, this statement can be considered adequate regarding the characteristics of theories. Another example of an explicit, adequate representation found in one of the introduction chapters is the following: "Even a theory—a system of scientifically founded, self-contradictory statements for describing, explaining and predicting reality—always remains tentative knowledge" (C-SII, Introduction, p. 14). In contrast, from the example of an implicit, adequate representation given in Table 4 (1B), one must derive the target NOS statement (i.e., empirical foundation and tentativeness of theories).

As theories are not hypotheses with an explanatory power to explain different phenomena, the example given in Table 4 (2A) shows a (partly) not adequate representation of theories in explicit manner. Following this representation, single hypotheses could become theories, or, in other words, theories are seen as former single hypotheses. This statement is problematic because it builds up misleading pictures both of hypotheses and theories. An example of an implicit and (partly) not adequate representation addressing theories is shown in Table 4 (2B). In the solution provided by the teachers' manual, it comes not clear how the process of *justifying correctness* is undertaken. Given the reference to an unexplained interpretation of the data provided in the teachers' manual, the representation remains implicit. It must be derived that theories cannot be regarded as absolutely "true" or "correct" but are tested within the framework of their tentativeness based on data analysis. Consequently, theories can only be regarded as "proven" in relation to the underlying data.

Table 4 Exemplary presentation of textbook statements on "Theories"

Category	Explicit	Implicit
Adequate	(1A) "The endosymbiont theory of the origin of mitochondria and chloroplasts is now generally accepted and extensively proven" (K-SII, Cell biology, p. 33)	(1B) *Task:* "Explain how these cytological findings support a theory about the phylogenetic origin of mitochondria in animal cells" (W-SII-L, Cell biology, p. 67) *Answer (provided by the teachers' manual):* "What is striking about the cytological findings is that bacteria do not have cholesterol in their membrane, but animal cells do. Since mitochondria only have cholesterol in their outer membrane, but not in the inner membrane, one may assume that these organelles are due to bacterial forms that were taken up by endocytosis. Thus, these findings support the endosymbiont theory" (Bayrhuber et al., 2019b, p. 11)
(Partly) not adequate	(2A) "If a well-founded hypothesis also has a great explanatory value for different phenomena, it becomes a scientific theory" (W-SII-B, Introduction, p. 10)	(2B) *Task:* "Justify with the help of Fig. 2 the correctness of the endosymbiotic theory.Fig. 2. Comparison data of endosymbiotic theory" (K-SII, Cell biology, p. 33) *Answer (provided by the teachers' manual)*: "These two organelles trace back to prokaryotes because they have similar genetic material, their own protein biosynthesis with 70–5 ribosomes […] and their inner membrane has a similar construction to prokaryotic membranes" (Bickel et al., 2018)

The abbreviations of the textbook sources (e.g., K-SII) are outlined in chapter 4.1; the original statements made in the textbooks were in German and may differ slightly from their original syntax

By use of the word "correctness," this task is not adequately representing theories as it implies characteristics of an absolute, irrefutable form of scientific theories.

5.3 Extent of Explicit NOS Representations (RQ 1)

It was expected that the textbooks contain a greater number of implicit than explicit representations (e.g., Park et al., 2020a, 2020b). The comparative calculation of the percentages of explicit and implicit representations per page revealed that a larger proportion of the representations are of implicit manner (Fig. 3).

It was further expected that the introduction sections of the textbooks contain a greater number of explicit NOS representations compared to the subject-related chapters (i.e., Cell biology, Genetics, Evolution; e.g., McDonald, 2017). The comparison of the proportions in different chapters revealed that in all introductory chapters, at least 50% of the NOS representations are presented explicitly, while in the subject-related chapters, there is only one chapter (Cell biology in K S-I) with 50% of the NOS representation shown explicitly. Most chapters, however, rather include implicit NOS representations (Fig. 3).

To compare the relative frequencies of explicit representations in the two groups of introduction chapters and subject-related chapters, the Mann–Whitney *U* test was applied. The calculation revealed a statistically significant difference in the average number of explicit NOS representations per page between the two groups with a high effect size ($U = 18{,}500$; $Z = -2{,}919$; $p = 0.002$; $d \geq 1.0$; Fig. 4).

5.4 Extent of Adequate NOS Representations (RQ 2)

It was expected that the textbooks include NOS representations, which are mostly at least in parts not adequate (e.g., Park et al., 2020a, 2020b). The group comparison of the average number of adequate and (partly) not adequate representations for the category "Scientific Practices" revealed this category being represented adequately with the highest frequency (2.2 representations per page on average) within the textbooks. By use of the Kruskal–Wallis test, a significant difference in the average number of the five main cognitive-epistemic FRA categories was revealed ($H = 75{,}530$; $p < 0.001$). The comparison of two of each of the five groups using the Mann–Whitney *U* test revealed statistically significant differences between almost all five FRA categories with high effect sizes ranging from $d = 0.898$ (comparison of "Methodological Rules" and "Knowledge") to $d = 3.315$ (comparison of "Scientific Practices" and "Methodological Rules"; Fig. 5). The calculations revealed two exceptions from this. The comparison of the categories of "Aims and Values" and "Methodological Rules" ($p = 0.396$) and "Aims and Values" and "Knowledge" ($p = 0.179$) shows no significant differences.

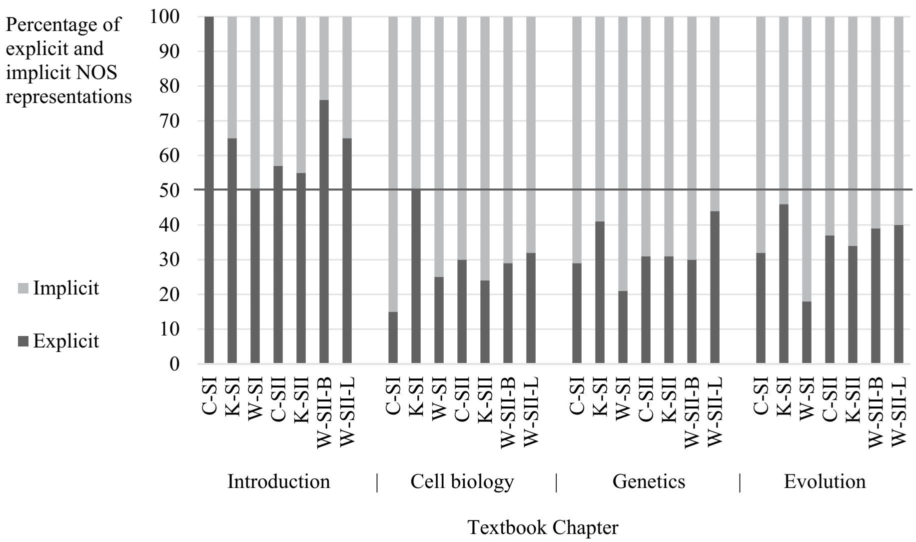

Fig. 3 Ratio of explicit to implicit representations across the chapters

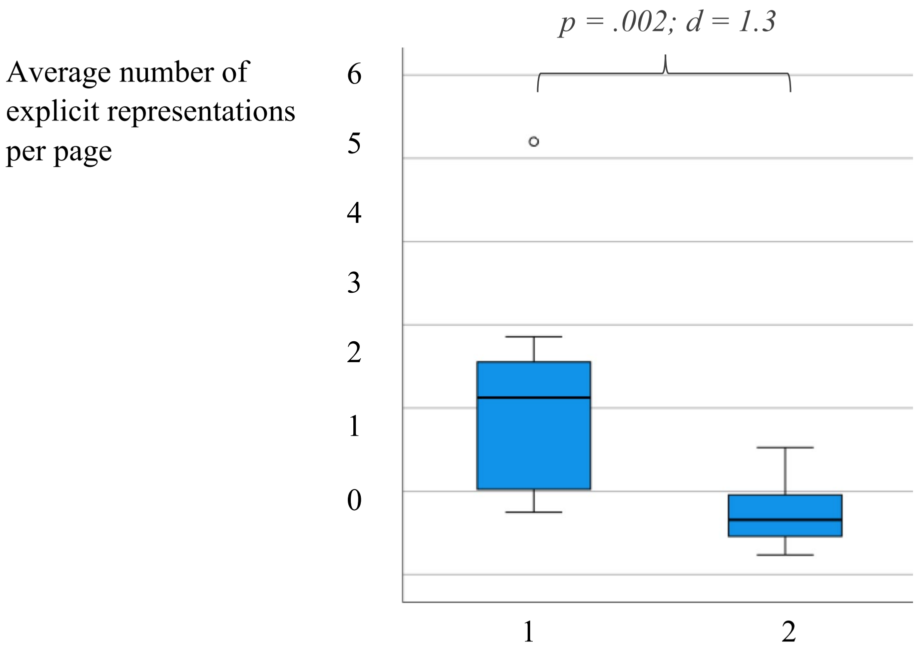

Fig. 4 Group comparison between the introduction chapters (1; $n=7$) and the subject-related chapters (2; $n=21$) of the seven textbooks considering only explicit (possibly including implicit) representations; outliner is marked by a white circle (○); median is marked by bold line

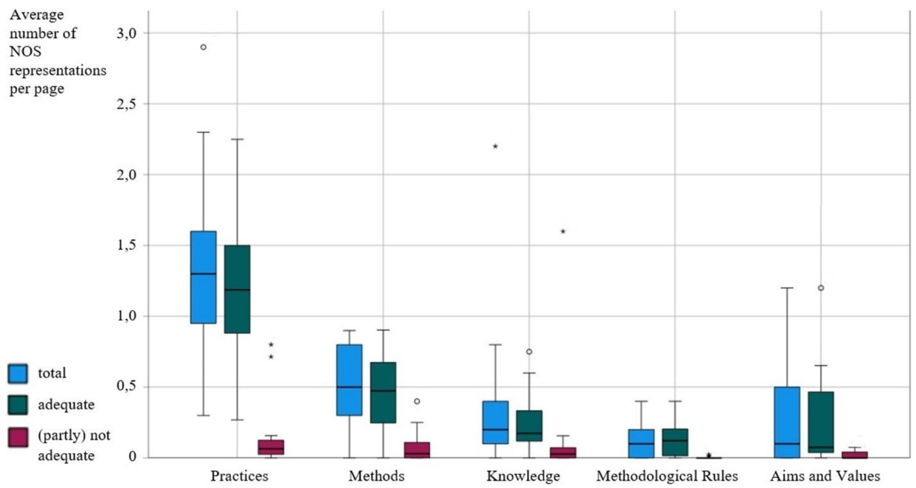

Fig. 5 Average number of NOS representations per page in the four chapters in each of the seven textbooks; outliers are marked by a white circle (○) and an asterisk (*); median is marked by bold line

6 Discussion

The study aimed to identify the extent and quality of NOS representations in biology school textbooks. With this, the questions of *what* and *how* NOS representations are included in school textbooks for secondary levels are addressed. Regarding the question of *what* NOS representations are included, we found that the contents of the five categories of the cognitive-epistemic system of science are presented unequally throughout the analyzed textbooks. "Scientific Practices" are addressed most frequently in the textbooks which is also in line with other studies analyzing the amount of NOS content in science curricula (e.g., Kaya & Erduran, 2016; Mork et al., 2022). It is striking that other studies on the number of NOS representations in science curricula from other countries also report on "Scientific Practices" being more frequently represented in comparison to other FRA categories. For example, Kaya and Erduran (2016) found for the Turkish curriculum that the numbers of representations of "Aims and Values" and "Scientific Practices" have a higher proportion compared to the other cognitive-epistemic categories. For the Norwegian curriculum, Mork et al. (2022) showed that "Scientific Practices" and "Social Values" are dominating aspects. The authors relate the finding of high frequency of NOS representations regarding "Scientific Practices" to the current landscape of science education and to international attention to "Scientific Practices" that has strengthened since the development of the Next Generation Science Standards in the USA. The national educational standards of Germany (i.e., KMK, 2020) also indicate that NOS aspects within the *intended curriculum* (Valverde et al., 2002) are addressed primarily in terms of "Scientific Practices." An analysis of the German educational standards (e.g., KMK, 2020) could provide insights into the distribution of NOS representations at another level of the curriculum. Such an analysis could also be the starting point for research into the connection between curriculum and textbook development.

6.1 *Manner* of Cognitive-Epistemic NOS Representations (RQ 1)

We expected that there is a greater number of implicit than explicit NOS representations in school biology textbooks (e.g., Park et al., 2020a, 2020b). We further expected that the introductory sections contain a greater number of explicit NOS representations compared to subject-related chapters (e.g., McDonald, 2017). The results regarding the extent of ratio of explicit and implicit representations are consistent with both expectations. By evaluating single NOS representations, it was shown that a larger proportion of the representations are of implicit manner (Fig. 2). This is in line with comparable textbook analyses (e.g., BouJaoude et al., 2017; McDonald, 2017; Park et al., 2020a, 2020b; Park et al., 2020a, 2020b). The introductory chapters of the textbooks contain a significantly greater number of explicit NOS representations compared to the subject-related chapters (Fig. 4). Considering that textbooks serve teachers as a basis for the design of learning and teaching approaches and hence, "shape the nature of classroom interactions" (Remillard & Heck, 2014, p. 713), the role of textbooks in the process of shaping the implemented curriculum (Valverde et al., 2002) is notable: they provide, among others, contextualized content to be used for science education. If NOS representations within textbooks mainly remain implicit, then the responsibility of making them usable as materials for science class lies mainly with the teachers. Teachers would need to recognize and capitalize on them (Reinisch & Fricke, 2022; Leden et al., 2020). However, science education research has found that only few teachers are self-acquainted with NOS, and, consequently, rarely foster corresponding contents in science class (Lederman, 2007). It can be assumed that NOS aspects that are only implicitly presented in the textbook are less likely to be identified by teachers and consequently less likely to be addressed in the classroom.

Concerning effective NOS instruction, the addressed NOS aspects should be "taught with or within an existing applied context, providing students with the chance to see how a science theory is applied to real-world situations" (Scharmann et al., 2005). It was further found that a reflection of different NOS aspects in different contexts and at different levels of contextualization along a continuum is important to foster an adequate NOS understanding (Bell et al., 2016; Clough, 2006). Following this, a consideration of the abstract and concrete levels of representations (Abd-El-Khalick et al., 2008; Scharmann et al., 2005) is needed to reveal further understanding of how and to what extent the representations put emphasis on scientific (biological) research in general compared to contextualized aspects. Explicit (and adequate) NOS representations could be formulated on an abstract level in introductory chapters, in subject-related chapters on a concrete level. The contextualization of NOS representations could then connect the content of FRA categories to explicit, subject-related topics on a concrete level. To give an example, the statement "Even a theory—a system of scientifically founded, self-contradictory statements for describing, explaining and predicting reality—always remains tentative knowledge" (C-SII, Introduction, p. 14; A1, Table 3) can be used to derive subject-related statements regarding theories and tentativeness on a concrete level. For evolutionary biology, the following statement could be an example for that: "The basic features of Darwin's selection theory have since been confirmed by a wealth of facts and expanded by new findings, especially in genetics and population biology, to form the synthetic theory of evolution." Returning contextualized content in subject-specific biology class to abstract explanations of NOS aspects might help to make the abstract definitions more understandable. On the other hand, abstract explanations in the introduction chapter could help to reflect contextualized, subject-specific contents on a meta-level and to establish references to other context-specific contents. In this way, particular characteristics of certain NOS aspects regarding specific contexts could be elaborated.

6.2 *Adequacy* of Cognitive-Epistemic NOS Representations (RQ 2)

We expected that school biology textbooks include NOS representations, which are mostly at least in parts not adequate (e.g., Abd-El-Khalick et al., 2017) . The results regarding the adequacy of the representations are in sum not consistent with this expectation (Fig. 5). The analysis revealed that there is a greater number of adequate than (partly) not adequate representations. Considering different FRA categories (Fig. 5), it becomes clear that the NOS representations seem to be predominantly adequate, regardless of their content, which is in principle positive.

However, by means of this study, a reliable analysis approach enabled the identification of representations useful for the further improvement of NOS representations. By means of such improvement, identified implicit and (partly) not adequate representations can be transformed into explicit and adequate ones. For example, the student task "Please justify with the help of Fig. 2 the *correctness* of the endosymbiotic theory." (K-SII, Cell biology, p. 33; 2B, Table 3) can be used as a starting point to develop an explicit representation addressing the durable, but tentative characteristic of scientific knowledge and corresponding justifications within the process of gaining new, still changeable, and expandable knowledge. The following transformation gives an example: "Please justify with the help of Fig. 2 the rationale of the endosymbiontic theory as a comprehensive system of reasoned sentences based on measured data." This would also address the contents of related subcategories such as "Rejection or Change of Theoretical Constructs" and "Avoiding Ad-hoc Changes of Theoretical Constructs" (Table 1: "Methodological Rules"; Reinisch & Fricke, 2022), which would further address the characteristics of theories and corresponding ways of gaining valid scientific knowledge (Ruse, 2005). By means of developing explicit representations, the answer to the suggested task provided in the teachers' manual should then include corresponding aspects of justification. However, it is questionable whether *each* NOS representation within the textbook needs to be of explicit manner, as a sufficient number of explicit representations might be satisfactory in terms of representing relevant NOS aspects.

6.3 Limitations of the Study

The development of the category system for evaluating single NOS representations (Table 3) was done using selected criteria, which are also included in a scoring rubric for evaluating the quality of whole textbooks (Abd-El-Khalick et al., 2008). Due to the theoretical and empirical grounding as well as to the alignment of the process to the research objective (i.e., determining the evaluation unit as a single representation instead of whole textbooks, evaluating criteria without rating them by giving scores, selecting the criteria of manner and adequacy, merging consistency to adequacy, and not considering completeness), we assume that the category system is coherent with the characteristics of the FRA and the corresponding requirements for its use in qualitative analyses. However, it can be assumed that with the help of the category system (Table 3), the quality of individual NOS representations cannot be evaluated as a whole since the criteria of *completeness* and *adequacy* are related. As outlined above, the results regarding *adequacy* might be different under consideration of the criterion of *completeness* since single incomplete representations could result in a misleading picture of a NOS aspect.

An analysis of the quality of NOS representations is inferential and affected by the bias of the involved coders, which affects the reliability of this study (Chua et al., 2019). Regarding the initial scoring rubric, Abd-El-Khalick et al. (2008) point out that "the rubric remains inferential" (p. 842). Even though several discussions regarding disagreements between coders and the calculations of interrater-reliability closely accompanied the analysis process, the data is still based on the estimation of the involved researchers.

The presented results rely on a relatively narrow sample size of only four chapters of seven biology school textbooks from Germany. Although the results are in line with other textbook studies (e.g., BouJaoude et al., 2017; McDonald, 2017; Park et al., 2020a, 2020b; Park et al., 2020a, 2020b), deeper insights into possible ways of contextualization require analyses of a broader sample (i.e., considering further subject-related chapters such as Neurobiology and Ecology).

This study focused on the analysis of cognitive-epistemic NOS representations. Considering the mutual interaction of the two systems of sciences (i.e., interactions between the cognitive-epistemic and the social-institutional system of sciences; Erduran & Dagher, 2014), the omission of FRA categories of the social-institutional system (e.g., "Social Interactions" and "Power Structures," Reinisch & Fricke, 2022; Erduran & Dagher, 2014) does not allow us to draw conclusions about the extent and quality of corresponding textbook representations. Investigating representations of the social-institutional system further promises a more accurate understanding of the portrayal of NOS in instructional materials, especially considering the contextualization as well as possible connections between the portrayals of the two systems of science (Cheung, 2020). For example, the identification of the quality of possible correlations between the FRA (sub-)categories of “Social Organizations and Interactions” and “Scientific Practices” (Reinisch & Fricke, 2022; Erduran & Dagher, 2014) might reveal insights into how the conduction of experiments are related to or controlled by social-institutional NOS aspects such as working in teams. This would help foster a more precise depiction of NOS in instructional material and hence students’ understanding of scientific inquiry as well as the role of scientists who are involved in that process. In this context, it could be examined to what extent the four categories of this study (explicit, implicit, adequate (partly) not adequate) can also be applied to social-institutional FRA categories.

7 Conclusion

In this paper, the questions of *what* and *how* NOS representations are included in the German biology curriculum (i.e., school textbooks for secondary levels) are addressed. It can be concluded that the results of the present study highlight the need for the improvement of NOS textbook representations to enable the implementation of explicit and adequate NOS interventions in science school textbooks (Allchin et al., 2014; Erduran & Dagher, 2014; Erduran, 2019). It can further be assumed that NOS textbook representations can be used for the design of future digital media serving as instructional materials (Reinisch & Fricke, 2022; see Ivić, 2019).

Regarding the question of *how* NOS representations addressing the cognitive-epistemic system of science are assumed to be introduced in science class, it can be concluded that the textbooks contain a greater average number of implicit than explicit NOS representations. This leads to the assumption that for the enhancement of instructional materials addressing NOS, the *manner* as a quality criterion is still important to be considered. Regarding *adequacy*, it can be assumed that none of the cognitive-epistemic NOS representations analyzed in this study addresses certain NOS specificities, which could indicate difficulties in the representation of those specificities. However, it is assumed that further analyses, which consider the *completeness* of NOS representations, reveal more detailed insights into the quality of the representations overall.

Regarding the methods in this study, it can be concluded that the use of some of the criteria of the scoring rubric (Abd-El-Khalick et al., 2008) was proven to be a reliable and valid tool for the qualitative analysis of single NOS representations, which stem from a biology textbook analysis by use of the differentiated FRA (Reinisch & Fricke, 2022).

Acknowledgements We thank the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) for funding the project Bio-NOS (project No. 423393239). Any opinions, findings, conclusions, or recommendations expressed in this study are those of the authors and do not necessarily reflect the views of the DFG.

Funding Open Access funding enabled and organized by Projekt DEAL.

Data Availability Not Applicable.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

Disclaimer Any opinions, findings, conclusions, or recommendations expressed in this study are those of the authors and do not necessarily reflect the views of the DFG.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Abd-El-Khalick, F., & Akerson, V. L. (2004). Learning as conceptual change: Factors mediating the development of preservice elementary teachers' views of nature of science. *Science Education, 88,* 785–810. https://doi.org/10.1002/sce.10143

Abd-El-Khalick, F., & Lederman, N. G. (2000). Improving science teachers' conceptions of nature of science: A critical review of the literature. *International Journal of Science Education, 22*(7), 665–701. https://doi.org/10.1080/09500690050044044

Abd-El-Khalick, F., Waters, M., & Le, A. (2008). Representations of nature of science in high school chemistry textbooks over the past four decades. *Journal of Research in Science Teaching, 45*(7), 835–855. https://doi.org/10.4324/9781315650524-6

Abd-El-Khalick, F., Myers, J. Y., Summers, R., Brunner, J., Waight, N., Wahbeh, N., Belarmino, J. (2017). A longitudinal analysis of the extent and manner of representations of nature of science in U.S. high school biology and physics textbooks. *Journal of Research in Science Teaching, 54*, 82–120. https://doi.org/10.1002/tea.21339

Bayrhuber, H., Drös, R., & Hauber, W. (Eds.) (2019a). *LINDER Biologie SII. Gesamtband. Lehrbuch für die Oberstufe [LINDER biology for higher secondary level. Complete volume. Textbook for the senior level.]* Braunschweig: Schroedel.

Bayrhuber, H., Drös, R., & Hauber, W. (Eds.) (2019b). *LINDER Biologie SII. Gesamtband. Lösungsheft [LINDER biology for higher secondary level. Complete volume. Solutions to the exercises.]* Braunschweig: Schroedel.

Bell, R. L., Mulvey, B. K., & Maeng, J. L. (2016). Outcomes of nature of science instruction along a context continuum: Preservice secondary science teachers' conceptions and instructional intentions. *International Journal of Science Education, 38*(3), 493–520. https://doi.org/10.1080/09500693.2016.1151960

Bickel, H., Lang, T., Riemer, U., & Stiehm, M. (Eds.) (2016). *Natura 7–10. Biologie G9-Ausgabe. [Natura 7–10. Biology edition for 9 years of secondary school.]* Stuttgart: Klett.

Bickel, H., Hell, L.-E., Langer, F., Stiegler, M., & Stiehm, M. (2018). *Natura Oberstufe. Biologie für Gymnasien. Lehrerband mit Kopiervorlagen. [Natura senior level. Biology for secondary schools. Teachers' manual.]* Stuttgart: Klett.

Bickel, H., Lang, T., Riemer, U., & Stiehm, M. (Eds.) (2020). *Natura Biologie Oberstufe. [Natura Biology senior level.]* Stuttgart: Klett.

BouJaoude, S., Dagher, Z. R., & Refai, S. (2017). The portrayal of nature of science in Lebanese ninth grade science textbooks. In C. V. McDonald & F. Abd-El-Khalick (Eds.), *Representations of nature of science in school science textbooks*. (pp. 79–97). New York: Routledge. https://doi.org/10.4324/9781315650524-4

Braun, J., Joußen, H., Paul, A., & Westendorf-Bröring, E. (Eds.) (2012). *Biologie heute SII. Erweiterte Ausgabe. [Biology today for higher secondary level. Extended version.]* Braunschweig: Schroedel.

Caramaschi, C., & Levrini & Erduran, S. (2022). Mapping the nature of science in the Italian physics curriculum: From missing links to opportunities for reform. *International Journal of Science Education, 44*, 115–135. https://doi.org/10.1080/09500693.2021.2017061

Chaisri, A., & Thathong, K. (2014). The nature of science represented in Thai biology textbooks under the topic of evolution. *Procedia: Social and Behavioral Sciences, 116*, 621–626.

Cheung, K. K. C. (2020). Exploring the inclusion of nature of science in biology curriculum and high-stakes assessments in Hong Kong. *Science & Education, 29*(3), 491–512.

Chiappetta, E. L., & Fillman, D. A. (2007). Analysis of five high school biology textbooks used in the United States for inclusion of the nature of science. *International Journal of Science Education, 29*(15), 1847–1868. https://doi.org/10.1080/09500690601159407

Chua, J. X., Tan, A.-L., & Ramnarain, U. (2019). Representation of NOS aspects across chapters in Singapore Grade 9 and 10 Biology textbooks: Insights for improving NOS representation. *Research in Science & Technological Education, 37*(3), 259–278. https://doi.org/10.1080/02635143.2018.1542377

Clough, M. P. (2006). Learners' responses to the demands of conceptual change: Considerations for effective nature of science instruction. *Science & Education, 15*(5), 463–494. https://doi.org/10.1007/s11191-005-4846-7

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Erlbaum.

DiGiuseppe, M. (2014). Representing nature of science in a science textbook: Exploring author–editor–publisher interactions. *International Journal of Science Education, 36*(7), 1061–1082. https://doi.org/10.1080/09500693.2013.840405

Erduran, S. (2014). Beyond nature of science: The case for reconceptualising 'science' for science education. *Science Education International, 25*, 93–111.

Erduran, S. (2022). Too philosophical, therefore useless for science education? *Science & Education, 31*, 563–567. https://doi.org/10.1007/s11191-022-00340-4

Erduran, S., & Dagher, Z. R. (2014). Reconceptualizing the nature of science for science education. Scientific knowledge, practices and other family categories. *Dordrecht: Springer*.

Erduran, S., Dagher, Z. R., & McDonald, C. V. (2019). Contributions of the family resemblance approach to nature of science in science education. A review of emergent research and development. *Science & Education, 28*(3–5), 311–328. https://doi.org/10.1007/s11191-019-00052-2

Field, A. (2018). *Discovering statistics using IBM SPSS statistics*. Sage.

Fritz, C. O., Morris, P. E., & Richler, J. J. (2012). Effect size estimates. *Journal of Experimental Psychology: General, 141*(1), 2–18. https://doi.org/10.1037/a0024338

Hausfeld, R. & Schulenberg, W. (Ed.) (2016). Bioskop. SI. Ausgabe für Rheinland-Pfalz. [Bioscope. Lower secondary level. Edition for Rheinland-Pfalz]. *Braunschweig: Westermann.*

Irzik, G., & Nola, R. (2011). A family resemblance approach to the nature of science for science education. *Science & Education, 20*(7–8), 591–607. https://doi.org/10.1007/s11191-010-9293-4

Kaya, E., & Erduran, S. (2016). From FRA to RFN, or how the family resemblance approach can be transformed for science curriculum analysis on nature of science. *Science & Education, 25*, 1115–1133. https://doi.org/10.1007/s11191-016-9861-3

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching, 39*(7), 551–578. https://doi.org/10.1002/tea.10036

KMK. (2020). *Bildungsstandards im Fach Biologie für die Allgemeine Hochschulreife [Educational standards in biology for the general higher education entrance qualification].* Wolters Kluwer.

Koksal, M. S., Cakiroglu, J., & Geban, O. (2013). The effect of explicit embedded reflective instruction on nature of science understandings in advanced science students. *Journal of Biological Education, 47*, 208–223.

Krüger, D., & Riemeier, T. (2014). Die qualitative Inhaltsanalyse – eine Methode zur Auswertung von Interviews [The qualitative content analysis – a method for evaluating interviews]. In D. Krüger, I. Parchmann, & H. Schecker (Eds.), *Methoden in der naturwissenschaftsdidaktischen Forschung [Methods in science education research]* (pp. 133–145). Springer. https://doi.org/10.1007/978-3-642-37827-0_11

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics, 33*(1), 159–174. https://doi.org/10.2307/2529310

Leden, L., Hansson, L., & Ideland, M. (2020). The mangle of school science practice: Teachers' negotiations of two nature of science activities at different levels of contextualization. *Science Education, 104*, 5–26. https://doi.org/10.1002/sce.21553

Lederman, N. G. (2007). NOS: Past, present, and future. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 831–880). Lawrence Erlbaum Associates.

Lederman, N. G., & Lederman, J. S. (2014). Research on teaching and learning of nature of science. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 600–620). Routledge.

Lederman, N. G., Wade, P., & Bell, R. L. (1992). Assessing understanding of the nature of science: A historical perspective. In W. F. McComas (Ed.), *The Nature of Science in Science Education.* Dordrecht: Springer. https://doi.org/10.1007/0-306-47215-5_21

Leienbach, K.-W. (Ed.) (2016). *Biosphäre. Band 7–9 Gymnasium Nordrhein-Westfalen. [Biosphere. Edition for classes 7–9 of secondary school in Nordrhein-Westfalen.]* Berlin: Cornelsen.

Mayring, P. (2014). *Qualitative content analysis: Theoretical foundation, basic procedures and software solution.* https://nbnresolving.org/urn:nbn:de:0168-ssoar-395173

McDonald, C. V. (2017). Exploring representations of nature of science in Australian junior secondary school science textbooks. A case study of genetics. In C. V. McDonald & F. Abd-El-Khalick (Eds.), *Representations of nature of science in school science textbooks* (pp. 98–117). New York: Routledge. https://doi.org/10.4324/9781315650524-5

Mork, S. M., Haug, B. S., Sørborg, Ø., Ruben, S. P., & Erduran, S. (2022). Humanising the nature of science: An analysis of the science curriculum in Norway. *International Journal of Science Education, 44*(10), 1601–1618. https://doi.org/10.1080/09500693.2022.2088876

NGSS Lead States. (2013). *Next generation science standards*. National Academy Press.

Park, W., Wu, J.-Y., & Erduran, S. (2020). The nature of STEM disciplines in the science education standards documents from the USA, Korea and Taiwan focusing on disciplinary aims, values and practices. *Science & Education, 29*, 899–927. https://doi.org/10.1007/s11191-020-00139-1

Park, W., Yang, S., & Song, J. (2020). Eliciting students' understanding of nature of science with text-based tasks: Insights from new Korean high school textbooks. *International Journal of Science Education, 42*, 426–450. https://doi.org/10.1080/09500693.2020.1714094

Ramnarain, U. D., & Chanetsa, T. (2016). An analysis of South African Grade 9 natural sciences textbooksfor their representation of nature of science. *International Journal of Science Education, 38*(6), 922–933. https://doi.org/10.1080/09500693.2016.1167985

Reinisch, B., & Fricke, K. (2022). Broadening a nature of science conceptualization: Using school biology textbooks to differentiate the family resemblance approach. *Science Education.* https://doi.org/10.1002/sce.21729

Remillard, J. T., & Heck, D. J. (2014). Conceptualizing the curriculum enactment process in mathematics education. *ZDM Mathematics Education, 46*(5), 705–718. https://doi.org/10.1007/s11858-014-0600-4

Reutlinger, A., Schurz, G., & Hüttemann, A. (2019). Ceteris paribus laws. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy.* Stanford University. https://plato.stanford.edu/entries/ceteris-paribus/

Rosenberg, A. (2008). Biology. In S. Psillos & M. Curd (Eds.), *The Routledge companion to philosophy of science* (pp. 511–519). Routledge.

Ruse, M. (2005). Theory. In H. J. Sandkühler (Ed.), *The Oxford Companion to Philosophy*. Oxford University Press.

Scharmann, L. C., Smith, M. U., James, M. C., & Jensen, M. (2005). Explicit reflective nature of science instruction: Evolution, intelligent design, and umbrellaology. *Journal of Science Teacher Education, 16,* 27–41. https://doi.org/10.1007/s10972-005-6990-y

Schizas, D., Psillos, D., & Stamou, G. (2016). Nature of science or nature of the sciences? *Science Education, 100*(4), 706–733. https://doi.org/10.1002/sce.21216

Schreier, M. (2014). Varianten qualitativer Inhaltsanalyse: Ein Wegweiser im Dickicht der Begrifflichkeiten [Ways of doing qualitative content analysis: disentangling terms and terminologies]. *Forum: Qualitative Social Research, 15*(1), 59. https://doi.org/10.17169/fqs-15.1.2043

Spendrin, K. (2019). Qualitative Inhaltsanalyse in der Erforschung von Kompetenzanforderungen Ein Forschungsbeispiel zur Analyse von Anforderungssituationen didaktischen Handelns. [Qualitative content analysis in research of qualification requirements. An example of the analysis of situational demands in didactics]. *Forum Qualitative Sozialforschung, 20*(3), 14. https://doi.org/10.17169/fqs-20.3.3351

Valverde, G., Bianchi, L., Wolfe, R., Schmidt, W., & Houang, R. (2002). According to the book: Using TIMSS to investigate the translation of policy into practice through the world of textbooks. *Kluwer Academic*. https://doi.org/10.1007/978-94-007-0844-0

Van Dijk, E. M. (2011). Portraying real science in science communication. *Science Education, 95*(6), 1086–1100. https://doi.org/10.1002/sce.20458. https://doi.org/10.1007/978-3-030-15671-8

VERBI Software. (2019). MAXQDA 2020 (computer software). VERBI Software. https://www.maxqda.com

Weber, U. (Ed.). (2016). *Biologie Oberstufe SII. Gesamtband [Biology senior level. Complete volume].* Berlin: Cornelsen.

Wei, B., Li, Y., & Chen, B. (2013). Representations of nature of science in selected histories of science in the integrated science textbooks in China. *School Science and Mathematics, 113*(4), 170–179. https://doi.org/10.1111/ssm.12013

Wei, B., Jiang, Z., & Gai, L. (2021). Examining the nature of practical work in school science textbooks: Coverage of the diversity of scientific methods. *Science & Education*. https://doi.org/10.1007/s11191-021-00294-z

Zhuang, H., Xiao, Y., Liu, Q., Yu, B., Xiong, J., & Bao, L. (2021). Comparison of nature of science representations in five Chinese high school physics textbooks. *International Journal of Science Education, 43*, 1779–1798. https://doi.org/10.1080/09500693.2021.1933647