STUDENTS' BELIEFS ABOUT THE DIACHRONIC NATURE OF SCIENCE: A METAPHOR-BASED ANALYSIS OF 8^{TH}-GRADERS' DRAWINGS OF "THE WAY OF SCIENCE"

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ABSTRACT

In this paper we present the theoretical background, methodological considerations and preliminary results of a drawing-based instrument called TWOS (The Way Of Science). It is designed to assess students' views on the nature and development of science by asking them to draw the way (or trail) of science. The data-base additionally comprises students' written comments and interviews. Data analysis is based on the idea that this activity lets students produce metaphors, which express their beliefs about change and development in science. TWOS aims at avoiding specific problems that often accompany the exclusive use of open-ended paper and pencil tests or interviews. These methods rely on a certain level of linguistic competence in order to gain valid results. Numerous scholars have recommended the use of history of science to promote views about science as tentative, changing and developing. Such a general view on the NOS presumes a diachronic perspective on science (occurring over time). This perspective comprises beliefs about the general nature of change and development in science, about the stability and development of its methodological foundations, its epistemic strategies as well as its social organization and cultural embeddedness. Current research instruments usually put less emphasis on an explicit assessment of the diachronic aspects of science, even less in an historical context. As a consequence, it is not very well understood until today, if or how students' beliefs, attitudes and cognitive biases in reasoning about the past, their pre-instructional views on history in general and on past science in particular interact with each other and which kind of belief or belief-systems on the diachronic nature of science finally result from such an interaction.

OVERALL BACKGROUND OF THE STUDY

Numerous science educators all over the world share the vision of promoting students' understanding not just *of* science, but also *about* science[1] (Laugksch & Spargo, 1996; Matthews, 2000; Songer, Lee, McDonald, 2003; Hodson, 2009). In this respect, conceptualizations of scientific literacy include students' abilities and inclination to reflectively apply scientific process skills (observing, communicating, classifying, measuring, inferring and predicting), socio-epistemic activities (publication and public accreditation, forming communities and societies, awards and prizes for outstanding research) as well as skills of decision-making in socio-scientific issues (Kolstø, 2001). A widely shared goal among science educators is to investigate and enhance students' beliefs about the nature of science[1] (NOS) and scientific inquiry (NOSI).

Numerous valuable approaches of teaching science aiming at a better understanding of the NOS have been discussed (McComas, 2000; Lederman, 2007; Clough & Olson, 2008; Kishfe, 2011; Wong, Wan & Cheng, 2011). Problems and limiting factors on their implementation have been analyzed (Lederman, 2004; Höttecke & Silva, 2010). Among others, various strategies of purposively integrating the history and philosophy of science (HPS) in science teaching have been suggested (Matthews, 1989; Stinner, McMillan, Metz, Jilek, Klassen, 2003; Henke, Höttecke & Rieß, 2009; Höttecke, Henke & Rieß, 2010). Proposals to teach the NOS with HPS aim at successful development of scientific knowledge, of adequate epistemological understandings of science, of process skills, of beneficial attitudes towards science and a grasp of the place of science within its cultural and societal contexts (Seker, 2007). It has been argued that an appropriate use of the history of science can promote knowledge about the NOS and scientific processes in the above mentioned sense (Solomon, Duveen, Scott, 1992; Allchin, 1997; Abd-El-Khalick & Lederman, 2000; Galili & Hazan, 2001; Rudge & Howe, 2004; 2009). During the recent decades science studies as well as history of science have put strong attention on science as an epistemic endeavor building on human practice and social activity (Shapin & Collins, 1989; Shapin, 1994; Knorr-Cetina, 1999; Hacking, 2004; Daston & Galison, 2007; Rheinberger, 2007). In the aftermath of this movement instructional activities for science teaching have been suggested, to teach *about* processes of scientific inquiry and socio-epistemic activities like observation, documentation, validation or justification. They include a strong focus on contexts of emergence, consolidation and elaboration of scientific knowledge *and* practices as a rich resource for teaching science in a historical context (Prestes, 2007; Barth, 2010; HIPST). Such approaches use historical arguments mainly to foster learning of and about methods and processes of science, albeit with mixed success: Solomon and colleagues recognized that students' "[...] life-world motley of images of scientists and scientific activities had been augmented, but not displaced, by a few stories from history. This had added a raw new epistemological element to their thinking" (Solomon, Duveen & Scott, 1994, p.370). It has to be noted, though, that it seems quite unlikely to achieve effective learning about aspects of the NOS with "a few stories from history". Instead, there is a growing body of arguments and evidence in favor of the use of historical case-studies, which include explicit reflective activities on those aspects of the NOS (Allchin, 2011; Henke, forthcoming).

In order to foster NOS understanding by using HPS, various themes can be addressed during science lessons. Below we present a selection of key-questions, which address students' beliefs about change and development in science and factors influencing these processes.

- What exactly is meant by "change", "development" or "progress" in science?[2]
- Does science change as a whole or do the diversifying effects of individuals, research groups, disciplines, paradigms or general assumptions matter more?
- (How) is change in science related to social, political, economic or technological developments?
- How do refutations, revolutions, paradigm shifts or controversies interact with the course of science?
- What forms of cooperation, communalism or critique are typical for science and how have they changed their role and function over time?
- Do the methodological underpinnings of science ever change or are they durable?

Instructional strategies seriously focusing on these kinds of questions need to be informed by research on students' beliefs about the diachronic (occurring over time) dimensions of science. The term "diachronic" is well established in the history of science (Kragh, 1987). We use it here in order to demonstrate that our understanding of the NOS points to a variety of possible NOS-views of students depending on the historical context in which they appear. Research focusing on general aspects of science like the tentativeness of its terms, concepts and models or the formal separation of a scientific law from a scientific theory (like the VNOS does; Lederman, Abd-El-Khalick, Bell & Schwartz, 2002) is less helpful here. Students may estimate the role of such general aspects of science depending on the time-frame they think about. Students' views of the tentativeness of scientific knowledge for instance may vary, if they will either imagine science in the 17th or in the 21st century. Students' may regard past science as having a different "nature" than contemporary science. We are aiming at an instrument for assessing students' views on the NOS depending, if it has been taught in a context of contemporary science or with HPS. As we do not expect the NOS to be a set of timeless features independent from any context, we do not expect students' ideas about science lacking this diachronic dimension either.

Until today students' views on dynamic aspects of science have been conceptualized as either referring exclusively to changes in scientific knowledge, characterizing students' ideas as domain-specific epistemological beliefs (Hofer, 2006), or as referring exclusively to aspects of scientific inquiry, characterizing these ideas as views about scientific inquiry (Schwartz & Lederman, 2008). But students' ideas about change and development in science may also represent beliefs about change in its methodological foundations and epistemic strategies as well as transformations in its social und institutional organization, its place within culture or its relation to technology and society. As an additional consequence, success of historically informed instructional strategies for teaching science should consider students' beliefs about and attitudes towards history, especially history of science. How these beliefs influence learning about the NOS in an historical context or how they resonate with specific conceptions of the diachronic NOS is not sufficiently explored until today.

OVERVIEW OF THE STUDY

This study reacts on current and persisting demands for conveying a process view of science in the classroom on different time scales (Duschl, 1990; Wang & Marsh, 2002). Its general aim is to broaden the scope of current assessment of students' beliefs on the NOS. Therefore, a new instrument based on metaphorical drawings ("The Way of Science") for assessing students' beliefs on the diachronic nature of science will be presented and justified. Our study focuses a group of German 8th grade middle-school students (N=29). The dimensions of analysis include

- specific narrative structures[3] employed by students "talking history" (Pandel, 2002; Schreiber, 1999)
- beliefs about factors influencing change and development in science and how and why this happens
- beliefs about the ontological character of scientific knowledge.

The study leads to a typology of ideal types of belief-sets, which will be constructed deductively on the basis of theoretical considerations and results from earlier research as well as inductively on the basis of qualitative data-analysis. This paper explains and discusses the methodical and analytical procedures used in achieving valid statements about students' beliefs about the "nature" of change and development in science. We give more room than usual to the procedural aspects of this study in order to maximize the methodological generalizability of the procedures here to other contexts of research (Payne & Williams, 2005; Metcalfe, 2005; Mayring, 2007).

Data-analysis is based on three kinds of data: students' drawings of the way of science, their written comments on their drawings and transcripts of individual follow-up interviews. Separate analysis and triangulation based on all three kinds of data and the use of a metaphorical setting for data-gathering are the main methodological differences between our study and traditional approaches. Paper-pencil test or open-ended instruments like the VNOS (Views of Nature of Science Questionnaire; Lederman, Abd-El-Khalick, Bell & Schwartz, 2002) typically use follow-up interview data primarily for validating interpretations based on written responses. The variety of instruments for assessing beliefs about the NOS has been discussed (Lederman, Wade & Bell, 2002; Lederman, 2007) elsewhere. Critical remarks concerning ecological validity and educational fruitfulness of these approaches have been presented by Allchin (2011).

RESEARCH ON THE NOS BASED ON STUDENT-GENERATED DRAWINGS

This study utilizes students' drawings about the general topic "development of science" to gain insights into students' beliefs about the diachronic NOS. Within research on beliefs about the NOS, most studies using students' drawings employ the "Draw A Scientist Test" (DAST), founded by the work of Mead and Metraux (1957). In a recent review about its applications and modifications in the last half decade Finson (2002) concludes, that it continues to be a useful instrument giving insight into students' ideas and attitudes about science. Referring to drawings-based assessments, Finson states that "the combination of drawings with interviews appears to be the most useful of these strategies. [...] These instruments thus far appear to be valid tools regardless of subjects' ages, race, or gender"(Finson, 2002, p.341).

The use of drawings can also be beneficial for students with low self-esteem in science. Writing assignments are in danger to be understood by the students as a test of their science content knowledge. Moreover, using student generated drawings combined with subsequent interviews as a data-basis may also capture the perspectives of students with low reading or writing abilities, whose written answers are often impossible to interpret validly.

To derive additional methodological considerations for this study, we consulted textbooks and reviews on the subject of analyzing children's drawings as well as relevant publications in psychology and educational research. We found that drawing-based instruments generally vary according to two dimensions: the elicited drawings' *representational mode* and the *level of inference* regarding the analysis of the drawings (King et al., 1994; Reiß, 2000). Table 1 pictures this two-dimensional classification scheme.

Research in this field usually is based upon three different kinds of representational modes of drawings-based assessments (Kaufmann, 1980; Leisen, 1998):

a) *Realistic*, indicating, that the elements of the drawing are depictions of real-world situations, objects and their relations

b) *Symbolic*, pointing to drawings of diagrammatic, iconic or semantic representations of (functional, procedural, logical etc.) relationships, classificatory systems, models or concepts
c) *Metaphoric*, indicating, that the drawing consists of elements “referring to a set of concrete relationships in one situation for the purpose of facilitating the recognition of an analogous set of relations in another situation” (Ogden cited by Beck, 1973, p.84)

The level of inference is related to variations of the analytical rationale used to achieve meaningful interpretations of drawings. It refers to the relevance of theoretical considerations during data-analysis. A high level of inference is given for example, if a study considers the assessment of a psychological construct like attitude, which is expected to be indicated by specific elements of a drawing like color choice or image composition. The specific elements usually have been drawn either from theoretical considerations or from earlier research. Analysis at high levels of inference can be controlled by the use of pre-established checklists or tutorials for *deductively* classifying characteristics of a drawing into abstract, *explanatory* categories based on the theoretical concepts in focus. A low level of inference is preferable instead within an *inductive* research design. Here contents of a drawing will be compared, grouped and arranged into more general systems of classification. The individual classes, often achieved using grounded theory methodology, can be condensed into checklists consisting of *descriptive* categories used for enhancing further assessments. The explicit-implicit distinction of different levels of inference is best understood by an example: To assess, what a sample of students might think about the every-day life and activities of particle-physicists we might ask them to draw one physicist’ visual diary depicting specific objects and activities characterizing his occupation. Data-analysis might then compare, group and classify these objects and activities *explicitly* visible in the drawings. On the other hand, in order to assess these students’ attitudes towards a particle-physicist’s life and work, one should start looking for *implicit* characteristics. Here, one will use a coding-scheme for categorizing activities as “pleasant” or “unpleasant”, based on theoretical considerations instead of explicitly visible elements of the image. In the first case the level of inference was low, in the second it was high.

		Representational Mode		
		realistic	symbolic	metaphoric
Level of Inference	high/ implicit	“Draw a Person/Tree”	*explanatory/deductive analysis* diagrams, charts, model based drawings, concept-mapping *descriptive/inductive analysis*	“Draw a Bridge”
	low/ explicit	DAST & DAST-C		“The Way of Science”

Table 1: Typology of the use of images in research on students’ ideas

The following paragraphs will illustrate the two dimensions (inference and representation) and their characteristics.

The DAST (Chambers, 1983) for example, especially in combination with the "Draw A Scientist Test Checklist" (DAST-C) (Finson et al., 1995), prompts students to produce *realistic, lifelike representations.* The drawings may contain elements like light bulbs, which may symbolically indicate scientific ingenuity. Symbolic objects still fit into the realistic modes of representation, since they can be regarded as a means for displaying immaterial characteristics of objects or as pointing to stereotypical reasoning (e.g. messy clothes = social maladjustment). The level of *inference* in this test is generally very *low* and comparability of results is enhanced by the widespread use of the standardized checklist mentioned above, consisting mainly of descriptive criteria. The students write short explanations for their drawings or are interviewed thereafter. The analysis of this data is *explicit* to the effect that the interpretation is mostly interested in reconstructing the literal meaning of elements of students' drawings.

The psychological “Draw a Person” test is an example for a more *implicit* framework within the same representational mode (and even the same object to draw). Several scoring systems have been developed serving different analytical purposes (Abreu, 2006). Nevertheless, the various indicators are not based on the literal, subjective meaning of the images' elements. Instead they introduce an additional layer of explanatory inference to allow for the assessment of constructs like attitudes towards science and technology (Zeyer & Kägi, 2010). Used in this way, images can provide insights into remnants of childhood traumata or various types of developmental retardation (Ables, 1971).

In the *symbolic mode* we often find research on students' conceptions (Ratcliffe, 1995) and the structure of conceptual knowledge (Edward & Fraser, 1983, Weber & Schuhmann, 2000). Quite obviously, research questions and theoretical perspectives determine the level of inference (King et al., 1994): Benson e. a. (1993), looking at students' conceptions on the atomic or particulate nature of matter, asked them to draw a volume of gas based on a simple particle model of matter and descriptively classified the response types. In the same field Mikelskis-Seifert & Fischler (2003) used concept mapping techniques and took the maps' level of interconnectedness as a quantitative measure of the stability of students' conceptions.

Analyses of *metaphorical* drawings are built upon the assumption that culturally shared metaphors will be expressed by the drawings which correspond to the drawers' cognitive and emotional states (Berlin e. a., 1991). A drawing should therefore provide access to these states as long as researchers participate in the same pool of culturally shared metaphors. Although Lakoff and others provided cogent arguments supporting this assumption (Lakoff & Johnson, 1980; Lakoff, 1993), the level of inference in these approaches is bound to be very high. In the "Draw a Bridge" test for adolescents and adults for example, the psycho-emotional status of a person is inferred by exploring latent symbolisms and metaphoric meanings *post-hoc*, often without eliciting explanations from the person and without her/him being aware of the metaphoric setting. Moreover, communicative validation of the hypothetical findings is often not feasible (Hays & Lyons, 1981).

Our study is based on the assumption that all students of the sample are fully aware that all elements of their drawings (characteristics of ways) are expressions of transformed meanings about development of and change in science (see fig. 1). Students should therefore plan and regulate their drawing based on their intention to express their ideas about change and development in science in a coherent way.

The following section will provide some background on the use of metaphors in educational research and this study's rationale for analyzing students' metaphorizations.

METAPHORS AS A MEANS FOR EXPRESSING AND RECONSTRUCTING STUDENTS' MEANINGS

Muscari (1988) explicitly reflects upon the productive nature of metaphors for externalizing espoused beliefs and how metaphorical reasoning provides alternative pathways for integrating new experiences. According to him the "[...] unconventional semantics of metaphorical language executes certain functions of which literal language is unable to perform" (Muscari, 1988, p.423). He also states, that metaphors enable "dislodging us from fixed conceptual schemes, [...] helping us place our impressions into newly fashioned units of meaning". In science education metaphors have been successfully used as tools for solving a variety of problems. Contemporary research tends to explore metaphors *in* science (concept development and representation) as well as *about* science (nature of scientific knowledge): Metaphors serve for an analysis of students' or teachers' conceptions about their own knowledge (Seferoglu et al., 2009), about their views on learning and their metacognitive processes (Thomas, 2006) as well as their general perspectives on teaching (Ritchie & Russell, 1991). The development of specific beliefs about the NOS might also be influenced by the unintentional use of metaphors when teachers or students talk about science in the classroom (Schwartz, 2007).

Analysis of Metaphors as Reconstruction of Meaning

Figure 1 shows a common way of conceptualizing intentional metaphorization. Certain elements of a source domain are mapping onto elements of a target domain. This basic structure has been applied to our study and data analysis.

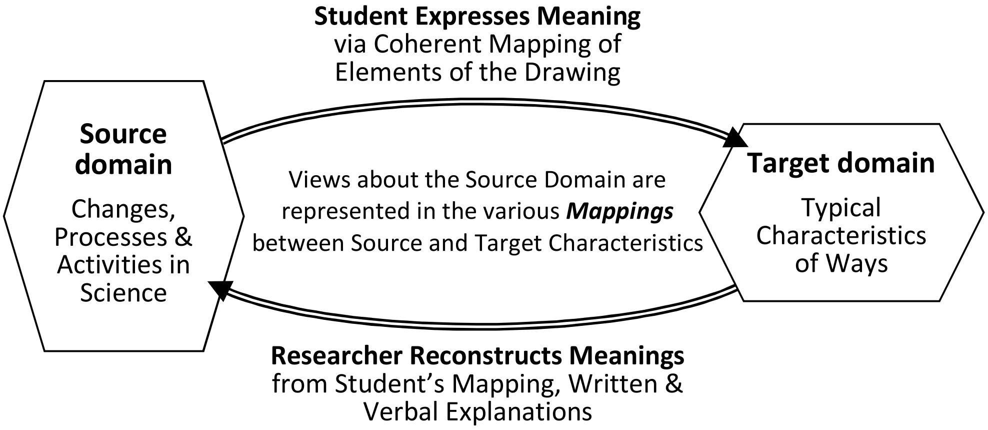


Figure 1: Reconstruction of students' meanings based on a source-target model of intentional metaphorization

It also indicates why the use of metaphors in the field of NOS research can be beneficial: The mapping-process does not rely on students' ability to verbalize their espoused beliefs about change in science, an ability which is often insufficient for providing useful data due to students' underdeveloped semantic repertoire for talking about complex and unfamiliar subjects like professional science. Also, the mapping process lets students spontaneously assign affective attributes to elements of the source domain (Moser, 2010) without the need for ad-hoc verbalization of their affective states. Accordingly, relying exclusively on verbalization of literal meanings leads to identifying students' beliefs as purely cognitive constructs, a position long abandoned in educational research (Rokeach, 1972; Pajares, 1992; Schommer, 1994). The use of metaphors also affects the types of reasoning used in presenting ones ideas: Beck et al. (1978) regards the specific benefits of metaphors in allowing for semantic as well as *analogical* reasoning. This type of reasoning is the base of many everyday reasoning processes (Vosniadou, 1989). An assessment eliciting the same processes for externalizing beliefs as were used for internalizing them might therefore provide information not accessible by other methods and lead to a more valid account of students' beliefs about development and change in science.

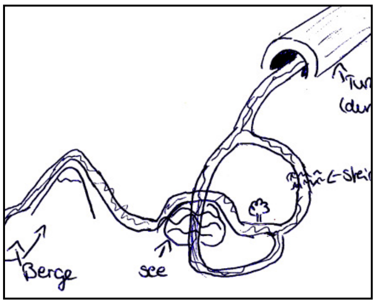
Moser (2010) states some generally accepted characteristics of metaphors guiding their use in research:

(1) *Metaphors influence information processing*, since different metaphoric models lead to different ways of interpreting new experiences.
(2) *Metaphors provide a reliable and accessible externalization of tacit knowledge*, since they have been used to generate valid linguistic or iconic representations of knowledge, which was otherwise not accessible.
(3) *Metaphors are holistic representations of understanding and knowledge*, since they involve distributed processing of knowledge, attitudes and beliefs producing more thorough views about a target domain.
(4) *Conventional metaphors are examples of automated action*, since they tend to circumvent self-presentation strategies and reflect subjective theories likely to guide actions referring to the source domain.
(5) *Metaphors reflect social and cultural processes of understanding*, since a limited amount of source domains convey understandings of a specific target. Different individuals/groups prefer different source domains.

Based on the source-target model of metaphors (fig. 1), some methodological preconditions can be established: To avoid undue influence of the target domain, it should provide a culturally fair, developmentally and cognitively appropriate topic, while ensuring students' emotional involvement with that topic should not constrain metaphorization. The latter would be the case, if we asked students to draw science as school building. The target domain should be fruitful, which means it has to be equally familiar to all students and complex enough to allow for a broad variety of different meanings. The conceptual structure of the target should therefore be as wide as possible, in order ensure its characteristics can resonate with cognitive as well as affective facets of students' beliefs about the source domain.

A successful metaphorical mapping is shaped substantially by the students' individual beliefs and their clear expression by individual choice of symbols. Each choice has to be interpreted with regard to the structure of the drawing as a whole: Stones or hills for instance may symbolize problems occurring during research, similar elevations in another student's way may express science's "distance to truth" at a specific time. The reconstruction of the underlying meanings has to take into account the contingency, context-dependency and everyday-character of symbols chosen (stone, hills, lakes, road signs etc.). Thus, each symbol has its place in an individuals' conceptual and metaphorical framework and its intended meaning has to be reconstructed accordingly. As a result, researchers must hermeneutically reconstruct these idiosyncratic meanings. They do this by analyzing and re-analyzing the metaphorical mappings of each element of the drawing in *isolation* and in *relation* to other temporarily established sets of meanings based on other elements of the target domain. This hermeneutical procedure should not base its inferences solely on students' images. Written and/or oral explanations as well as follow-up interviews have to be taken into account as well, to ensure valid and adequate reconstruction (Maxwell, 1992). We lower the level of inference by including in our reconstructive analysis only those mappings explicitly addressed during follow-up interviews. Global properties of the drawings like background color, artistic qualities and the like are not taken into account in our analysis.

Figure 2 illustrates the analysis of metaphors in our study. It shows a short section of a students' narrative compiled as reconstruction of meanings generated from of a section of a student's drawing.



Scientists of the past [*single, structured path* as collective entity of scientists whose activities and experiences represent science itself] **had to master *typical problems* of science** [*recurring hills* as externally inflicted hindrances represented by insufficient scientific instruments and procedures]. **When approaching a *difficulty* on their research** [*lake* as difficult question about a natural phenomenon] ***some* of them decide to avoid this difficulty** [*crutch* as possibility for scientists to depart from the collective enterprise] **by following an *easier path* avoiding the question** [*obstacle-free road, changing direction* as opportunistically chosen research alternative], **while a *single scientist*** [*separate road* as idealistic researcher] **decided to solve this problem *once and for all*** [*crossing the lake* as irrevocable research activity resulting in finalized knowledge]. **The other scientists *do not behave like him* resulting in serious *problems*** [*stones* as internally inflicted hindrances represented by lack of personal experience] **in their research afterwards. Close to our present, they choose to *collaborate*** [*merging roads* as merging of individual experiences and previous knowledge in collective research], **since they decided to *explore unknown territory*** [*road entering a dark tunnel* as future research areas where no previous knowledge and/or ideas yet exist].

Figure 2: Section of a student's narrative about their way of science (bold), including reconstructed meanings (in parentheses)and the corresponding section of the drawing

SAMPLE AND DATABASE

Participants of this study were German middle school students of age 14-15. They attend the 8th grade of a German "Gymnasium" comparable to secondary school. We are well aware that the representativeness of this group is limited, since only 4 of the 29 students were female. Moreover, the participants took a significant part of their non-science classes in English ("bilingual classes") hinting at above average language abilities.

A short questionnaire was handed out to the students, asking them to draw their idea of "the way of science" in a blank space. Various trials of the drawing-activity with students of the same age group exposed their tendency to conflate *change in science* with the notion of an ahistorical, generalized *method of science* (e.g. "idea->experiment->result"). We therefore chose to include several minimally guiding statements, resulting in the following instruction: *"Think of science as a way, or trail, starting long ago. Please draw your way!"* To assert a shared understanding of the item's metaphoric character, the instruction explained the possible way as being *"narrow or broad, steep or flat, even or uneven … or everything else that fits your ideas about the way of science through time"*. Students were prompted to write detailed comments on their image below their own drawings. A second question asked the students, if scientific knowledge changes along the "way" and how and why these changes may occur. The question aims at exposing possible inconsistencies between students' beliefs on the diachronic NOS and the epistemological characteristics they assign to scientific knowledge.

After completing the questionnaire, each student was interviewed by one of five trained interviewers. The interviewers were instructed to first let the students explain their drawings in depth. Guiding comments or questions were not to be asked during this phase. In a second step the interviewers were advised to ask for the meaning of elements of the drawing not included in the students' explanation. They were trained to use a restricted set of explicative questions like *"What do you mean by …?"* or *"Could you please talk a bit more about …"*. Similar to the methodology used by Carey et al. (1989) the interviewers had memorized a list of expressions expected to emerge in the interview, in order to "unpack" them by using questions of the type mentioned above. These expressions included words like "progress", "change", "problems" or "success" in order to clarify unexpected or ambiguous meanings and to access students' beliefs about causal structures behind incidents of change in science on different scales. Research shows, that students tend to reproduce commonly held stereotypic views in a first drawing, but may show more elaborated views when asked to draw the image anew (Finson, 2002). Therefore students were asked at the end of the interview, if they like to add, remove or change any of the elements in their drawings. This question also served to control for learning processes that may have been induced by the interview itself or due to the extended use of a single metaphor (Evans & Evans, 1989).

To maximize the generalizability of our methodological procedures to applications in other contexts, we simulated the use of the resulting instrument with students influenced as well as uninfluenced by historically informed science teaching. To achieve this, two datasets were obtained from one group of students before and after an eight-week teaching intervention using three different historical case studies[3]. This was done in the course of the HIPST-Project (Höttecke, Henke & Rieß, 2010), meaning the students experienced HPS-based science teaching, conducted experiments on replications of historical instruments while the lessons were characterized by intentional, explicit-reflective learning opportunities on various aspects of the NOS (Henke, Höttecke & Rieß, 2009). It was ensured that the students had no previous experience with historically informed science teaching beyond experiences that we expected to be part of "traditional" science lessons like occasionally presented biographical information or anecdotes. It was also ensured that history classes the students took directly before the pretest or parallel to the intervention did not include teaching-sequences explicitly referring to science or science related issues.

Pre- and posttest-data were analyzed independently in order to prevent mutual influencing during inductive analysis (see below). For the construction of a typology both datasets were merged and membership to pre- or post-dataset was anonymized.

METHODOLOGICAL CONSIDERATIONS

In this section a methodological rationale of the study will be developed. The theoretical dimensions for a thorough analysis of students' views about change and development in science will be described.

The analysis begins with the student's narratives about their ideas about the way of science (see fig. 2 for an example). The smallest units of analysis are the student's reconstructed meanings in the sense mentioned above. The meaning a student expressed was treated as arising from latent individual and subjective structures *and* as a product of the discourse (in this case the follow-up interview) of which it is an emergent feature (Geertz, 1974). Analyzing students' written answers and interview transcripts was done according to the methodology of qualitative content analysis (Mayring, 2010). We were following a multistep procedure allowing for deductive as well as inductive categorization of data inspired by Galili's (2001) framework (see fig. 3). Our analysis is also informed by several studies in the field of history education (e.g. Borries et al., 1997).

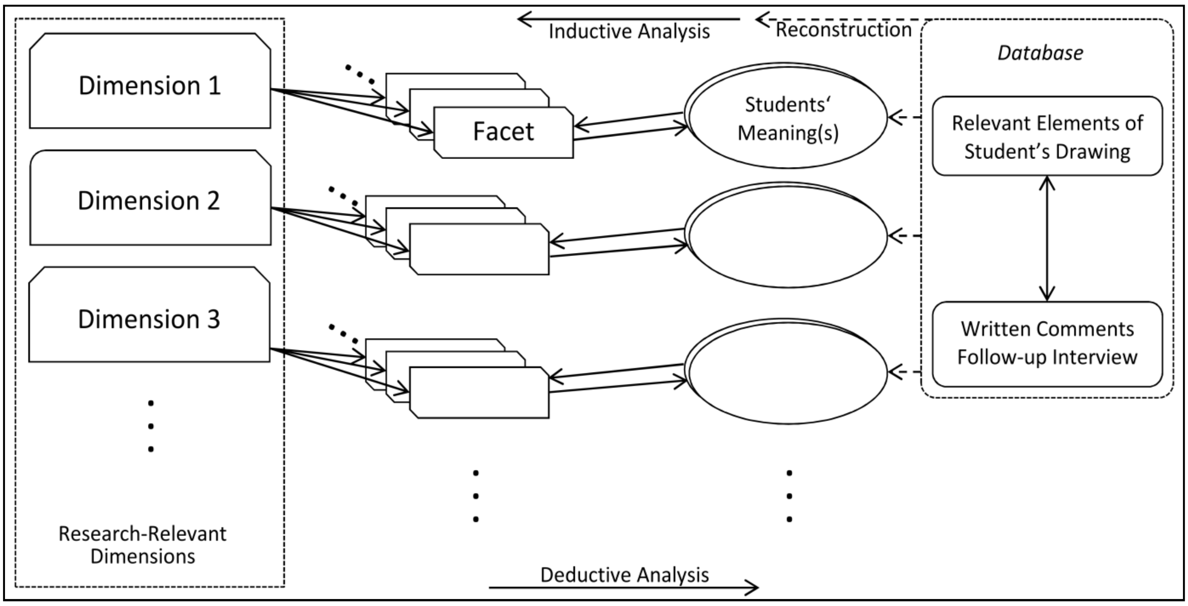


Figure 3: Framework for inductive-deductive reconstruction of students' meanings

The general idea is to start with a set of broad, analytically derived dimensions which have to be capable of describing, categorizing and differentiating students' views – their views on the epistemology of scientific knowledge for instance. These dimensions are grounded in our research interest and serve as an analytical framework for starting the reconstruction of students' meaning-making. All dimensions can be characterized by specific facets – different views about the stability of scientific knowledge through time for example. The whole variety of each set of facets belonging to one dimension has been generated in an inductive-deductive procedure. To give another example: the dimension *epistemological belief about scientific knowledge* may be characterized by *scientific knowledge as growing by recurring refutations and modifications of incorrect ideas* or by the view *scientific knowledge as growing by continuously adding-up new and correct ideas*. While the dimensions frame our research interests, the facets are strongly adapted to the contingencies of the process of students' meaning-making.

Quality and validity was negotiated between three researchers/experts in the field of NOS and students' beliefs as well as history education. They focused on:

(1) inference-to-meaning relations during the analysis of the students' metaphors
(2) soundness of theoretical perspectives used during deductive classification
(3) internal generalizability of emergent facets.

Table 2 presents an overview of all relevant dimensions and facets at-a-glance. The employed dimensions are described thereafter and illustrated by a selection of students' responses.

Dimension	Facets	Main data sources
Epistemological beliefs	knowledge accumulating (additive) knowledge accumulating (mending) refutation as basic mechanism (fruitful) refutation as dead end (error) science characterized by competing ideas science as succession of ideas *[non-disjunct dichotomic sets of categories]*	Written explanations Follow-up interviews
Ontological attitudes	science as uncovering nature's secrets science as inference for best explanation knowledge about nature is (in)finite knowledge about nature is (in)accessible scientific knowledge = technological artifacts *[non-disjunct dichotomic sets of categories]*	Written explanations Follow-up interviews
Factors	Type of factor, its location & evolution *[disjunct categories with shared scales]* (see Table 2)	Drawings, written explanations follow-up interviews
Narrative structure	traditional; genetic; circular; teleological; organic *[non-disjunct categories]*	Follow-up interviews
Metaphorization	science as a diffuse entity science as an evolving network *[disjunct categories]*	Drawings written explanations

Table 2: Dimensions and their facets relevant for data analysis.
The type of category used for qualitative analysis is given in square brackets.

Dimension 1 & 2: "Epistemological Beliefs" and "Ontological Attitudes"

Two commonly used dimensions of the NOS can be integrated in the analysis almost unchanged. They include epistemological beliefs about the development of scientific knowledge (Carey & Smith, 1993; Schommer-Aikens, 2002) and students' ontological attitudes towards science and scientific knowledge, more precisely students' beliefs on the accessibility and finiteness of scientific knowledge.

Students with a plausible ontological attitude, that there is a finite, predetermined amount of scientific knowledge to be "found out" over time oftentimes refer to significant achievements in the past:

> "[…] and then there came the great insights and found out nearly everything of what we know today. So today we cannot find out so much more." [written explanation of image, student code a6r5w, translation by author].

Many students regard nature as generally accessible through scientific methods. At the same time they justify the perceived limitlessness of the generation of scientific knowledge with self-propagating and self-correcting processes within science:

> "The way [of science] will never stop, since new research will open up new questions for scientists to answer" [written explanation of image, student code a0n6w, translation by author].

> "Scientific knowledge will change a lot in the future. And this change will never stop, since scientists will not stop researching, discovering, making new theories and explaining things in another way than how

> people thought was right before." [written explanation of image, student code a6e5w, translation by author].

Dimension 3: "Factors influencing change and development in Science"

The rationale for this dimension was adapted and expanded from a quantitative assessment of almost 20,000 European students' historical awareness (Borries et al., 1997). There, students were asked to rate a given set of abstract determinants according to their perceived potential to influence the course of history. In our study we have reconstructed and classified factors, which students perceived to influence change and development in science. Different *types of factors* can vary in their *location on a time-scale* (effective only in the past / in the present / enduring), their *evolution in time* (influence stable / rising / vanishing) and their *character* (hindering / supporting). Table 3 presents an overview of the results, indicating the character of influence for different types of determinants. For each type of factor the relative frequency of the respective variations in their location and evolution in time are indicated.

The types of factors and the character assigned to them indicate the expected overweight of a mixture of presentism and chronological snobbery. The former refers to the logical fallacy of equaling "later" and "better" (Fischer, 1970; Barfield, 1967). The latter rests on the fallacy of assuming that, in our case, characteristics of the nature of contemporary science were put there intentionally, by scientists only and at specific points in the past, albeit in their present form. Students therefore tend to ignore, that these characteristics are also co-produced along with contingent social and cultural processes (Jasanoff, 2004). Another issue is technology-centered optimism (Borries et al., 1997), reflecting the assumption that use, production and improvement of technological artifacts within scientific research and with the help of science is a main indicator of positive change. In total, supportive factors dominate slightly. The students see most of the hindering factors acting in the past only with a vanishing influence until today. Supportive factors show the opposite trend, albeit not as clear. More than twice as often they are regarded as having a stable influence over time.

Factors influencing change and development in science	**Location on a time-scale**			**Evolution of Influence**	
	past	present	enduring/stable	rising	vanishing
Religion/ Mysticism	– –	–	–		– –
Societal recognition of science	– *(lack of)*			+	
Failures & problems during research	– –				–
Technological artifacts	– – *(lack of)*		+	+ +	– – *(lack of)*
Research instruments		+		+	
Research strategies	– *(inadequate)*		+	+ +	
Previous knowledge	– – *(lack of)*	+ +	+		
Specialization/ disciplines		+		+	
Significant scientific achievements	+				+
Curiosity as main motive			+		

Character of factor indicated as ***+ (supportive) / – (hindering)***
relative frequency of occurrence in sample per row indicated by –(–) / +(+)

Table 3: Factors influencing change and development in science reconstructed from students' statements

Dimension 4: "Narrative Structures"

Rüsen (1982) pointed out that laypersons' and especially students' narratives about history do not follow traditional paths of causality. Due to the students' fragmented knowledge about relevant historical content knowledge their "talking history" has to be interpreted as a complex sense-making process. Within this process the students express what and why something might have happened in the past. They develop individual perspectives on the past while keeping a steady footing in the present. Such narratives are characterized by a linear temporal sequence of events and/or event-selectivity. The latter means that only those events are included into the narration, which are linked to other events already talked about or to topics regarded as important based on implicit assumptions and attitudes (Körber, 2007). It is highly plausible, that, if the subject to talk about is science, attitudes toward past science as well as personal ontological and epistemological assumptions will affect beliefs about the scientific enterprise as changing and developing. Research has indicated, that five main types of narrative structures can be found, which characterize and structure students' narratives about history: *traditional*, *genetic*, *teleological*, *organic* and *circular* structures (Pandel, 1995). They are relevant for teaching and learning history, but also serve as a pattern for describing students' narrative structures in our study. Their holistic nature can best be captured by the graphical representations presented in figure 3.

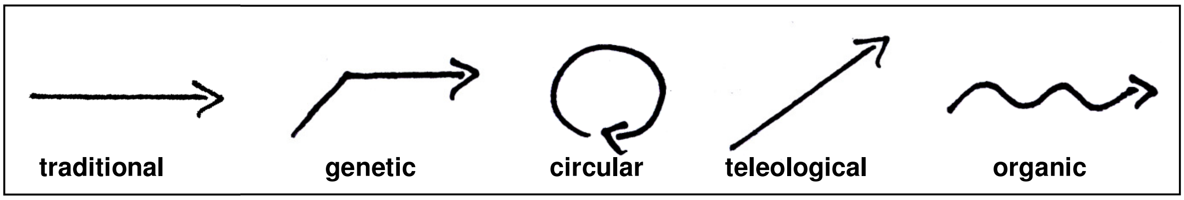


Fig. 3: Graphical representations of narrative structures about the historical development of a specific topic

- *A traditional structure*: science is characterized by a lack of qualitative changes in its characteristics or factors influencing its course. This does not mean, however, that research does stagnate or no new knowledge is constructed, but the general pattern of scientific activity does not change over time.

- According to a *genetic structure* change in science occurs only when a certain threshold or barrier has been overcome. Nevertheless, there is no causality or teleology implied: the necessary changes are not motivated by the threshold-to-pass, but are judged as necessary in retrospect.

  > "My drawing first shows a gravel road. This means that the progress in research was slow and difficult. They [the scientists] made assumptions, but these were ridiculed. This is what the mountain [drawn in the picture] means. It was very difficult to convince others [non-scientists in general] of one's theory. But as time has passed they found better arguments, and there were more ideas. Therefore, a mud road. The boardwalk means that there was evidence for the theories and they all began to do really exact research. Then the way turned into a road. This means that research is matured. Man has invented things, collected much evidence and set up better and better theories."

  This student expresses the view that - in retrospect - external (nonscientific) criticism had to be countered by sampling good evidence and thinking hard. This represents the barrier, which obviously has been passed, leaving science with a good stock of exact knowledge and methods to keep on working with. This genetic narration regards science as maturing internally (evidence and arguments) while reacting to external hindrances (disbelief).

- *Circularity* also represents a common structure. This narrative structure focuses on the idea that historical developments tend to follow a circular pattern. There may be immense qualitative changes and even apparent progress in science, but a final situation does somewhat resemble the starting point. This structure can attribute circularity to small as well as large scales of change in science.

  > "My way looks like this because in the beginning it was certainly very hard to find out things in science. Then it became easier, since there was knowledge to build upon. Today it gets harder again, since we try to find out newer and more astonishing things. And there is not much knowledge left for us to find out."

- *Teleological narrations ascribe* a goal orientation to change in science. Students’ propositions can therefore be validly transformed into the form “…happened/changed, in order to …”. We found that students’ expressions heavily build upon a teleological interpretation of the activities of scientists. Change occurs by pursuing small scale goals like solving the next problem/research question at hand and by orientation towards large scale goals like the perfection/finalization of the existing body of knowledge by correcting or adding to it. The lack of a technological or ecological *telos* is only surprising at first glance. Students were not asked straightforward for the higher goal(s) of science, instead their answers aimed at knowledge development or change in science.

  > “Change will go on, since there is still not everything explained what happens in nature.”

  > ”There will always be research and the knowledge will change again and again, since scientists try to find errors and fill out the gaps.”

- A narration following an *organic narrative structure* does emphasize recurring patterns and regularities in normal history. These patterns represent the internal logic of science, for example as ups and downs in productivity or as continuous problem-posing and problem-solving. Such an internal logic might be perceived as changeable by humans or as being natural and law-like.

These are the facets possibly shaping the dimension “narrative structures”. We found that the students did not make exclusive use of one of the narrative structures. Instead, they expressed different beliefs on the development of science by using specific sets and sequences of these structures.

Dimension 5: “Metaphorization”

This dimension captures incidents of consistent use of metaphors by students. Those, who metaphorize the "way of science" in similar ways, tend to use of similar elements in their drawings using them to represent similar beliefs about change and development in science. Our analysis is oriented close to established methods of metaphor analysis in psychology (e.g. Moser, 2000).

For pragmatic reasons we decided to limit this dimension to two distinct and inductively derived facets. Fig. 4 presents two exemplary drawings reflecting these two facets of metaphorization.

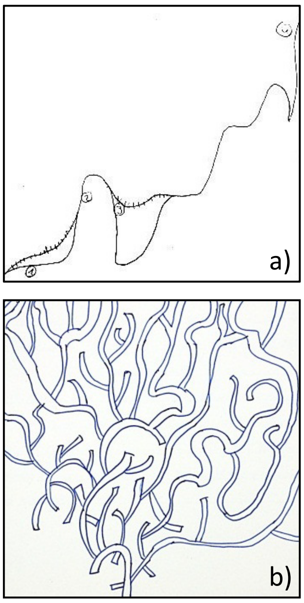


Figure 4:
Students’ drawings reflecting the views of a) science as one diffuse entity and b) science as an evolving network

The first facet represents the belief of *science as one diffuse entity*. Here, science is seen as reacting to internal or external perturbations as a whole. Students supporting this belief usually draw science as a single path without any branches, crossings or parallel developments. They tend to underestimate the role of collaboration, parallel lines of research or controversies in science. There is no preference for a specific narrative structure. Still, these students tend to prefer factors like religion/mysticism and do not mention the role of previous knowledge or the newly emergence of disciplines.

The second facet covers beliefs about *science as an evolving network.* Here, students picture science as an interconnected network of scientists at work or research groups, collaborating, criticizing or grounding their efforts upon others’ knowledge. These students tend to favor a traditional narrative structure, conveying the belief that these activities are typical and not likely to change over time. They tend to disregard factors like religion/mysticism and societal influences on science. The influence of individual failures and problems in research is a recurring topic in their narrations.

SYNTHESIS: THE WAYS OF SCIENCE - CONSTRUCTION OF IDEAL TYPES

The final result of this study is a typology of ideal types, which can be used as a heuristic device for analyzing students' beliefs about the change of science through time. On the basis of the results of our inductive-deductive analysis of students' responses, we have analyzed students' narratives again, looking for a more general scope on students' beliefs. We were aiming at a description of students' beliefs about the diachronic NOS, which had to meet seemingly opposing requirements. On the one hand, the analysis has to allow for the emergence of general, i.e. inter-individual and maybe even timeless patterns of beliefs. General patterns enable the identification of scientism, presentism, belief of an everlasting progress in science and the like. On the other hand, the analysis has to take highly idiosyncratic processes of students' meaning-making into account, which emerge as individual preferences for specific types of metaphors, symbols and their relations. Research based on qualitative data is commonly challenged by this dilemma (Kelle, 2005). As one tradition with a long track record in achieving a kind of agreement on the two opposing requirements, we use a highly structured version of the well-known method of constructing "ideal types" from qualitative data (Kluge, 2000). A similar methodology was deployed by Solomon and her colleagues (1994) in a study that aimed at describing of students' beliefs about the different roles scientists do represent.

Type No.	*„Change in science as ...*	**Basic narrative**
1	***... mining a limited resource"***	Scientists are effectively disclosing nature's secrets. The process enables true scientific knowledge. Since there is just a limited amount of still disclosed natural phenomena, there might be nothing left to discover anymore in the future. Therefore, scientific activities as we know them will terminate someday in the future.
2	***... finally growing up"***	Science of the past used to overcome external, societal and technological obstacles (e.g. mysticism, religion, lack of acceptance, inadequate materials). These obstacles weakened the powers inherent in science. Caused by extraordinary events or people (enlightenment, industrial revolution, genius scientists etc.) science broke free from constraints of the past. Science today instead is always ready to start exploring and produces correct knowledge about nature in this process. Therefore, old and erroneous ideas of past science are replaced by correct ones today.
3	***... Münchhausen-science[5]"***	Science used to struggle in the past with its internal inadequacies (e.g. inadequate research instruments and strategies, hasty conclusions, lack of collaboration). Then scientists produced or improved their epistemic tools (e.g. knowledge to build upon, effective methods etc.). Thus, science pulls itself out of a problematic situation. How stable and reliable the results of science are depends on the tools scientists use.
4	***... a story of dead ends"***	Science progresses by sacrificing those who have taken blind alleys instead of one single right path. Dead ends are representing scientific research that did not manage to produce expected results. With the wisdom of hindsight those approaches in science might be identified, which were or are bound to fail from the start. Therefore, the number of dead ends is declining with time.
5	***... sequential problem solving"***	Science produces knowledge effectively by solving problems successively. The problems may arise within science (e.g. conflicting evidence) or from the outside (e.g. stopping climate change), but are and will always be solved with success. The solutions science arrived at are unique and represent non-additive achievements.
6	***... objective technological progress"***	Science improves successively by producing technological artifacts, as we can see with our own eyes. The amount of this "knowledge" to be unveiled is infinite. Societal needs determine the direction of research in science and also the solvability of its problems.
7	***... creative science towards techno-science"***	Scientists of the past used to work hard and creatively. They had to do so, since many odds and ends prevented them from working successfully (e.g. lack of technology, materials, rationality etc.). The role of creativity and ingenuity is declining, since nowadays technology is more important and relieves scientist from the hard work they had to do in the past.

Table 4: Seven ideal types of students' beliefs about the diachronic nature of science

The construction of ideal types generally aims at the development of heuristic tools for analyzing processes of meaning-making and human behavior. Individual beliefs, meanings and decisions are transformed into a selection of a few expressive, abstract categories (Psathas, 2005; Hearn, 1975; Weber, 2009). In our study an ideal type is defined as a set each of the dimensions' facets and their interrelations. The students' predominant lines of argumentation and the beliefs they have expressed are reconstructed in terms of the facets characterizing each dimension. An ideal type therefore presents a second-order construct based on previous steps of data-analysis. It represents coherent sets of students' beliefs about the diachronic NOS (see fig. 2).

The reconstruction of an ideal type from students' ideas can best be illustrated by an example. If a student for instance has been identified as using a genetic narrative structure (dimension: narrative structure), he or she also tends to regard science as a collective enterprise (dimension: metaphorization). The next step is to look for students with a similar pattern and to investigate, if more facets of other dimensions might also consistently contribute to the ideal type. Looking at the data, two further ideas resonate with the pre-established set of facets: scientists are aiming at *disclosing nature's secrets* and thereby contributing to a *successively growing* body of true scientific knowledge (dimensions: ontological attitude & epistemological beliefs). In the next step one might find that students holding these beliefs also tend to see change in science as caused either by scientists struggling with *internal inadequacies* of science like inappropriate methods and instruments or by *external obstacles* like the lack of societal recognition (dimension: factors). At this point one has to re-check the existing interpretations, to decide whether the last finding really hints at the emergence of two distinct types. In this case, the next round of reconstruction begins. Validity of this process is reached by aiming at a high degree of theoretical plausibility on the one hand and by keeping a close connection to the data on the other (Kluge, 2000).

Progressing in such a way, the set of empirically related facets is continually growing while taking into account one dimension after the other. Nevertheless, the development of ideal types is not a result of a linear step-by-step procedure; the interpretative process described above is circular, since a high degree of internal consistency among the facets across all dimensions has to be achieved. This means that the choice of and relations among all facets representing an ideal type, have to be continually checked and re-checked against the data and already existing interpretations. The transformation process relies on *emphasizing and idealizing the relations between the facets*. As a result, an individual student's ideas about change and development in science do not need to fit exactly to any of the ideal types. A typology consisting of two or more ideal types is the result of circular process of *maximizing a type's internal consistency* as well as *maximizing its external discrimination* against all other types already reconstructed from the same data set. For this study, all interpretations and idealizations were discussed in order to maximize agreement among researchers. Disagreement or internal inconsistencies of the construction of ideal types can either lead to revision of the choices of facets and their relations, reorientation of the idealization procedure or re-analysis of data.

Table 4 presents a structured overview of ideal types we have reconstructed in our study. Brief descriptions represent each of the ideal types. We have found that some dimensions seemed to play a more prominent role for the students' meaning-making while others turned out to be of minor importance. The dimension *narrative structures* has framed many students' explanations during follow-up interviews. This dimension strongly interacted with students' *epistemological beliefs* regarding the scientific knowledge.

The resulting ideal types do enhance our understanding of the belief-systems of "non-ideal" students of our sample. Nevertheless, ideal types do not have to be exactly assignable to belief-sets of real and therefore "non-ideal" students since we consider their character as heuristic tools as a strength. Constant comparison to empirical data on students' beliefs on NOS from other studies (external validation) and continuous checking for counterfactual instances within datasets (internal validation) ensures an increasing validity of the resulting ideal types, which will allow moderate generalization even beyond the specific sample of this study.

CONCLUSION

The results of our study have indicated that the metaphor-based drawing test combined with the application of an ideal-type-methodology of data analysis provide a sound basis for the reconstruction of students' beliefs about the diachronic NOS. The students in our sample did not express any problems with understanding the activity, the method nor with producing a wide array of metaphors and symbols representing different aspects of the NOS. Nevertheless, it is currently not assured, if the TWOS-instrument can be used validly with students of other age groups than that of our sample. Thus, one should take into account that the developmental status and cognitive abilities of students strongly influence the metaphorical skills of younger children (supposedly until the age of 9) (Pierce & Chiappe, 2009, Vosniadou et al., 1984). Further research is therefore needed in order to test the validity of the TWOS-procedure for other samples than ours.

Students' beliefs about the diachronic NOS interfere with more general beliefs about history, past science and the NOS. Their interrelation has not been explored previously. The ideal types discussed here represent some preliminary evidence about such interferences. Nevertheless, we are aware of the problem that the number and character of dimensions we have used in our analysis as well as the data basis might be too specific or limited. It is at least a plausible, but not yet an evidence-based assumption that students' beliefs about the diachronic NOS do affect other dimensions of beliefs about the NOS.

Within a constructivist paradigm, teaching approaches based on the use of history of science like vignettes, stories, historical-investigative approaches or case studies have to consider these preconditions. Students' beliefs about the diachronic NOS structure their meaning-making about past science. Therefore, assessment of students' beliefs on change and development in science and the factors influencing them is becoming more important. According to our view research has not yet addressed this problem sufficiently. The methodology presented here and the types reconstructed in our study may serve as a starting point for further investigations on the diachronic NOS.NOTES

[1] Concerning the term "*The* Nature of Science" we have decided *for* the use of the definite article, since this is the most grammatical appropriate expression.

[2] The term "narrative" does not imply a specific type of text produced by students using a certain mode of narration evocated during data collection. Instead, we refer to the broader meaning of "narrative" as being a (e.g. textual) product of intentionally reporting a collection or sequence of events, showing a tendence towards (e.g. causal) interdependence, internal coherence, relation to a common topic and chronological order (Stone, 1979). The texts used for analysis are reconstructed to form this kind of narrative integrating information from students' drawings, written explanations and interview transcripts. Their reconstructedness and expository nature in no way prohibit the use of narrative structures to characterize the manner in which they are told.

[3] Comprehensive information on the case studies' historical contexts, learning goals and aspects of the NOS can be found on the homepage of the HIPST project (www.hipst.eu). The case studies used in the intervention represent the first three episodes of the thematic set "History of Electricity" and can be found here: *http://hipstwiki.wetpaint.com/page/history+of+electricity*

[4] Research concerning "change" in science has a long empirical as well as analytical tradition (see for example Niiniluoto, 1980; Laudan et al. 1986; Pera, 1994). The conception of change used here has to allow for classifying a broad range of students' ideas consisting of neutral and purely descriptive statements of significant differences between two points in time to highly axiological statements, referring explicitly to progress in science based on normative criteria for success or students' implicit assumption that "time makes all things better". The explicatory interview questions served to clear up the type of statement. Statements still unclear after discussion between experts were excluded from the parts of analysis, where a distinction between neutral and axiological ideas was essential.

[5] The Baron of Münchhausen is a figure from a German tale. He claimed to have saved his own life by pulling himself out of a swamp by his own hair.

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