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

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Abstract: *Numerous scholars recommend the use of history of science to promote adequate views about the nature of science (NOS). Such teaching episodes tend to focus on a diachronic (occurring over time) understanding of science, presenting knowledge, methods and organization of science as subject to change and development. Since students may hold inadequate beliefs about the development of science or regard past science as having a different "nature" than contemporary science, HPS education would benefit from a sound knowledge base about students' beliefs about the diachronic nature of science.*

In this paper we present the theoretical background, methodological considerations and preliminary results of a drawing-based instrument called TWOS (The Way of Science). TWOS is designed to assess students' views on the nature and development of science by asking them to draw, describe and explain science over time by metaphorizing it as a way (trail, path). Data analysis is based on the idea that this metaphoric activity lets students express their espoused beliefs about change and development in science while avoiding problems that often accompany the exclusive use of open-ended paper and pencil tests or interviews. The methodological and analytical procedures of TWOS are presented and discussed and its value as a research tool is justified in the context of its application to a group of 29 German 8th grade middle-school students.

Key-words: *education, history of science, qualitative data, ideal types, nature of science, epistemological beliefs, metaphors, metaphor analysis*

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1. BACKGROUND

Science educators all over the world share the vision of promoting students' understanding not just *of* science, but also *about* science (Matthews, 2000; Hodson, 2009). In this respect, conceptualizations of scientific literacy include students' abilities and inclination to reflectively apply scientific process skills like measuring, inferring or communicating, 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 (Laugksch, 2000; Kolstø, 2001).

In order to achieve these goals, science educators investigate ways to foster students' adequate beliefs about the nature of science (NOS) (McComas, 1998; Lederman, 2007; Clough & Olson, 2008; Khishfe, 2011) including strategies of purposively integrating the history and philosophy of science (HPS) in science teaching (Matthews, 1989; Stinner et al., 2003; Höttecke; Henke & Rieß, 2012). Empirical studies illustrate that an appropriate use of HPS can indeed promote adequate views about NOS 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 re-explored science as an epistemic endeavor building on human practice and social activity (Collins & Shapin, 1989; Knorr-Cetina, 1999; Hacking, 2004; Daston & Galison, 2007; Rheinberger, 2007), leading to the suggestion of instructional activities for teaching about processes of scientific inquiry and socio-epistemic activities like observation, documentation, validation or justification. They focus on contexts of emergence, consolidation and elaboration of scientific knowledge *and* practices and function as rich resources for teaching science in a historical context (Prestes, 2007; Barth, 2010). In short, they focus on what changes in science, to highlight aspects of NOS along this process.

The success of any approach using historical arguments to foster learning about NOS depends on students' prior beliefs about NOS. 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 et al., 1994, p. 370)[1].

In order to foster adequate NOS understanding by using HPS in science education various topics can be addressed. Below we present a selection of key questions that address the topic of change and development in science from various perspectives. Questions like these serve as starting point for explicitly and reflectively discussing epistemological, ontological, methodological and social features of scientific research.

[1] It has to been noted, though, that it is quite unlikely to achieve effective learning about 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 NOS (Allchin, 2011; Henke, 2012).

- What exactly do we mean by “change”, “development” or “progress” in science?
- How do refutations, revolutions, paradigm shifts or controversies shape the course of science over time?
- How is change in science related to social, political, economic or technological developments?
- What forms of cooperation or critique are typical for science and how have they changed their role and function over time?
- In what way does science change as a whole; in what way does change happen on the level of individuals, groups, disciplines, paradigms or general assumptions?
- In what way do the methods of science change; in what way is there a general way of doing science?

Students’ views about change and development in science have been predominantly conceptualized as domain-specific epistemological beliefs about changes in scientific knowledge (Hofer, 2006; Priemer, 2006). On the other hand students’ ideas about dynamic aspects of science may (and should) also concern other aspects of change, for example the diversification of its methods and epistemic strategies, transformations in its social and institutional organization, its shifting position within culture and society and its controversial relation to technology (Laudan et al., 1986; Ziman, 2000).

Students may hold a variety of - possibly conflicting - views about aspects of NOS depending on the context in which these aspects appear (Zeidler, Walker, Ackett, & Simmons, 2002). It is therefore plausible for them to also think differently about NOS depending on the time frame in question. As NOS is far from being a fixed set of features independent of time and context, students’ ideas about science cannot be expected to lack a diachronic dimension either.

Science instruction focusing on the above mentioned topics needs to be informed by research on students’ previous beliefs about the diachronic[2] (occurring over time) dimensions of science. For instance, students' previous views of the tentativeness of scientific knowledge may vary, if they will either imagine science in the 17th or in the 21st century. Their beliefs may develop differently, if tentativeness will be discussed in a context of contemporary or past science. As an additional consequence, success of historically informed instructional strategies for teaching science will depend on students' beliefs about and attitudes towards history, especially history of science.

What these beliefs about the diachronic NOS are and how they influence learning about NOS in an historical context is not sufficiently explored until today. There are persisting demands for conveying a process view of science in the classroom on different time scales (Duschl, 1990; Wang & Marsh, 2002). Nevertheless, current instruments for assessing students' views on NOS neither differentiate these views in the diachronic dimension, nor do they assess students’ views about change other than change in knowledge (Lederman; Wade & Bell, 2002).

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[2] The term “diachronic” is well established in the history of science (Kragh, 1987), referring to the (comparative) analysis of developments over historically relevant intervals of time.

The aim of this paper is to broaden the scope of current assessment of students' beliefs on NOS. Therefore, a new instrument and procedure, called "The Way of Science" (TWOS), will be presented, aiming at assessing students' beliefs on the diachronic nature of science based on metaphorical drawings. This paper explains and discusses the methodological and analytical procedures used in achieving valid results about students' beliefs about the "nature" of change[3] in science. More room than usual is given to the procedural aspects of this study in order to maximize the methodological generalizability of the techniques used here to other contexts of research (Payne & Williams, 2005; Metcalfe, 2005; Mayring, 2007). Specifics of the TWOS will be presented and justified in the context of its application to a group of 29 German 8th grade middle-school students.

2. STUDENT-GENERATED DRAWINGS AS RESEARCH TOOLS

Within research on beliefs about NOS, most studies using students' drawings are based in one way or another on the "Draw a Scientist Test" (DAST), founded by the work of Mead and Metraux (1957). In a review of its applications and modifications over the last half-decade Finson (2002) concludes that it still continues to be a useful instrument giving insight into students' ideas about and attitudes towards science. Referring to drawings-based assessments in general, he 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, who might frame writing assignments as tests of their science content knowledge. Moreover, using student generated drawings combined with subsequent interviews as a data-base may also capture the perspectives of students with low reading or writing abilities. Their written answers might otherwise not be interpreted with a sufficient degree of validity (Glyn & Silk, 1990).

2.1 Methodological Decisions in Drawings-Based Research

To derive additional methodological guidance for constructing and administering TWOS, we consulted textbooks and reviews on the general 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 their *level of inference* and their *representational mode* (see Figure 1). Cross-cutting methodological decisions concern the use of *inductive* or *deductive* analytical procedures and the objective of *describing* a drawing's content or *explaining* its intrapersonal origins (King; Keohane & Verba, 1994; Thomas & Jolley, 1998; Reiß, 2012).

[3] 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 allows for a broad range of students' ideas; from neutral descriptions of differences between two points in time to axiological statements about progress in science based on normative criteria for success. Follow-up interviews served to clear up the type of statement; they were excluded from the analysis, where a distinction between neutral and axiological statements would lead to a fundamentally different interpretation.

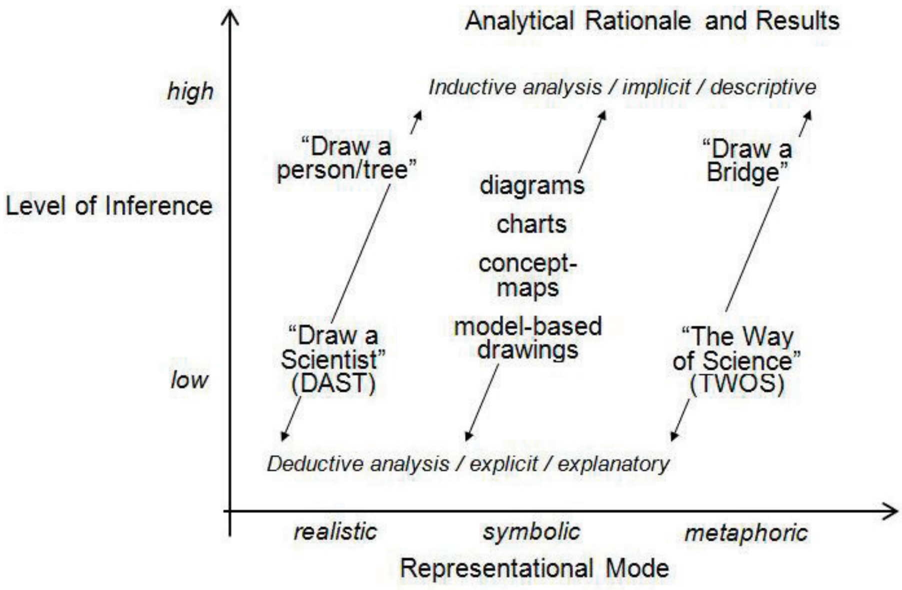

Fig. 1: Dimensions of methodological decisions in drawings-based research.

1) <u>Level of inference</u>
   The level of inference applied indicates the size of the inferential step between a drawing's surface-level content and its interpretation by a researcher. The level of inference is determined by the research questions in focus, by the methodology of interpretation and by the amount of theoretical and explanatory vocabulary introduced during analysis (King; Keohane & Verba, 1994):
   a) Studies showing a *high* level of inference assess psychological traits indirectly. A researcher might for instance infer from the choice of color or the general composition of a drawing that a child might hold certain attitudes towards certain objects or persons on its drawing. There is a strong tendency for deductively classifying characteristics of a drawing into abstract, explanatory categories based on the theoretical concepts in focus. Validity in this case is usually achieved through the use of pre-established checklists, clear-cut tutorials for raters, and by theoretical argumentation.
   b) Studies showing a *low* level of inference employ rather inductive research designs. Certain elements of a drawing will be compared, grouped and arranged in order to construct a general system of descriptive classification. The generation of categories is often based on the application of the methodology of grounded theory. Categories usually are arranged into checklists, which might guide further data analysis with a higher level of inference.
   c) The level of inference applied depends on a researcher's choice of either an explicit or an implicit mode of data analysis. An example: To assess students' ideas about particle-physicists' every-day life and work, the students might be asked to draw a visual diary of such a physicist. It will contain certain objects and display specific activities, which indicate the students' ideas on this issue. Data-analysis might then compare, group and classify these objects and activities *explicitly* visible in a drawing

(low level of inference). *Implicit* characteristics, on the other hand, may point out latent traits. In this case objects or activities displayed might be interpreted as “pleasant” or “unpleasant” based on theoretical considerations, allowing for hypotheses about students’ attitudes towards science (high level of inference).

2) Representational mode

Research using drawings as data usually elicit three different kinds of representational modes (Kaufmann, 1980; Leisen, 1998):

a) *Realistic* drawings, where the elements of the drawing are depictions of real-world situations, objects and their relations.

Examples: The Draw a Scientist Test (DAST; Chambers, 1983) for example, prompts students to produce realistic, lifelike representations of scientists and their workplace. The drawings may also contain allusive elements, hinting at immaterial characteristics of objects or persons (e.g. a scientist’s messy clothes allude to his/her social maladjustment). In combination with the "Draw a Scientist Test Checklist" (DAST-C; Finson; Beaver & Cramond, 1995) consisting mainly of descriptive criteria, the level of inference in the DAST is generally low. The students’ written or oral explanations for their drawings are analyzed explicitly to the effect that the interpretation is based on the literal meaning of elements of students' drawings. The “Draw a Person” test used in psychological research is an example for a more implicit framework. Several scoring systems have been developed serving different analytical purposes (Abreu, 2006) like inferences in childhood traumata, developmental retardation (Ables, 1971) or students’ attitudes towards science and technology (Zeyer & Kägi, 2010).

b) *Symbolic* drawings, where diagrammatic, iconic or semantic elements illustrate classificatory systems, models, concepts and their relationships.

Example: Here we often find research on students’ conceptions (Ratcliffe, 1995) and the structure of their conceptual knowledge (Edwards & Fraser, 1983; Weber & Schuhmann, 2000). Benson, Wittrock and Baur (1993) have explored students’ various ideas on the particulate nature of matter, asking students to draw a volume of gas using a particle model. Concept mapping has been used mainly for advancing, but also for assessing semantic structural knowledge about the nature of science (Ruiz-Primo & Shavelson, 1996; Hand, Lawrence & Yore, 1999).

c) *Metaphor-based* drawings, where the elements of the drawing “refer 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” (Beck et al., 1978, p. 83).

Example: The “Draw-a-Bridge”-test for adolescents and adults is a metaphorical drawing instrument with a high level of inference. The psycho-emotional status of a person is inferred by exploring their drawings’ latent symbolisms and metaphoric meanings *post-hoc*, often without additional explanations from the person and sometimes without her/him being aware of the metaphoric setting. Communicative validation of the findings is therefore often not feasible (Hays & Lyons, 1981).

In contrast, during the TWOS procedure proposed in this paper the students are fully aware that the elements of their drawings of ways project their meaning onto the domain of science. Figure 2 shows a section of typical metaphorical drawing produced by applying TWOS. Here, science and its development is symbolized by a rocky, curvy trail winding its way over hills, around and above lakes, splitting and merging and finally disappearing into a dark tunnel.

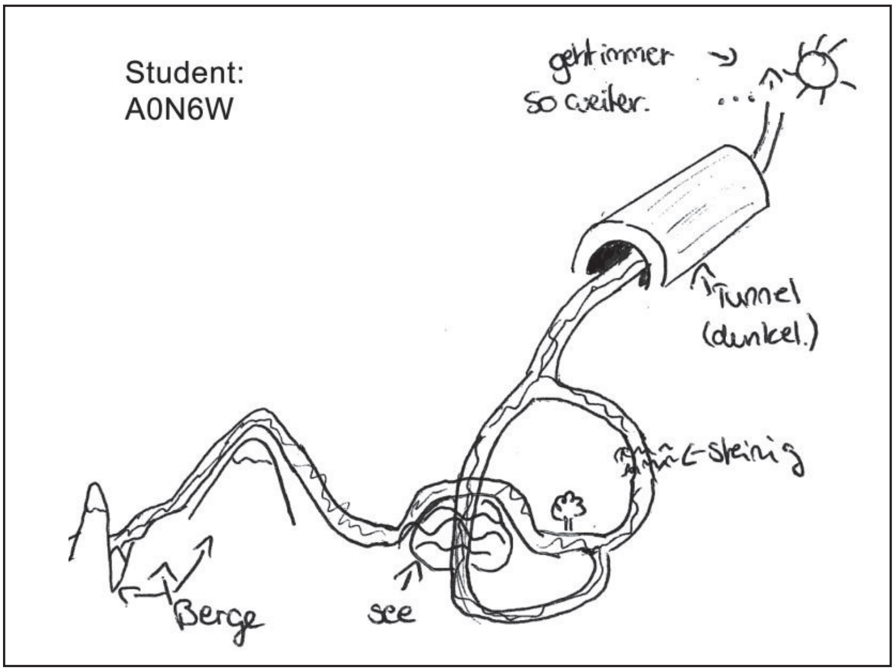

Fig. 2: Section of a student’s drawing about the way of science.

2.2 Using Metaphor-Based Drawings

Metaphors are widely used as tools for social, psychological and educational research. Moser (1999), for instance, uses the “way” metaphor to determine beliefs about the transition from university to work. Muscari (1988) stresses the productive nature of metaphors for the expression of espoused beliefs, since the "[...] unconventional semantics of metaphorical language executes certain functions which literal language is unable to perform" (Muscari, 1988, p. 423). Metaphors facilitate the production of relations of meaning between tangible objects or events (“source”) and abstract conceptions or notions (“target”). Moser (2000, pars. 11-16) states some generally accepted characteristics of metaphors, which may guide their suitable use in educational research:

(1) *Metaphors influence information processing*, since different metaphors ead 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 mental processing of content knowledge, attitudes and beliefs, allowing for more thorough expression of ones views about a target domain.

(4) *Conventional metaphors of everyday life are examples of automated action* - they tend to circumvent strategies of self-presentation and reflect subjective theories likely to guide one's actions.
(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.

Metaphors facilitate the analysis of students' or teachers' conceptions about their own knowledge (Seferoglu; Korkmazgil & Ölçü, 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 NOS might also be influenced by the unintentional use of metaphors when teachers or students talk about science in the classroom (Schwartz, 2007).

Metaphorical drawings can be a beneficial tool in the field of NOS research, since they depend less on students' ability to verbalize their espoused beliefs. Written or oral assessments typically run into problems due to students' underdeveloped semantic repertoires and a lack of experiences with professional science (Allchin, 2011). The process of metaphorization allows students to express emotions related to the target domain without the need for ad-hoc verbalization of their affective states (Moser, 2000). Thus, the use of metaphors as a research tool takes into account that students' beliefs cannot be reduced to purely cognitive constructs (Rokeach, 1972; Pajares, 1992; Schommer, 1994). Finally, Beck *et al*. (1978) point out the specific benefits of metaphors in allowing for semantic as well as analogical reasoning. While the former is typical for written and oral assessments, the latter is close to everyday reasoning (Vosniadou, 1989). Therefore, the assembly of metaphorical drawings with written or oral questionnaires like TWOS covers a wide range of different kinds of reasoning.

We suppose that students produce each element of a metaphorical drawing intentionally and meaningfully. The drawing process during administration of TWOS is planned and regulated based on the students' intentions to coherently depict change and development in science by reifying it into a way or path. We assume metaphors to be coherent systems of conceptual analogies (Kövecses, 2002), which presupposes a model of intentional metaphorization as shown in figure 3. For the use of TWOS we consider metaphorical drawings to be influenced by the students' beliefs about the diachronic nature of science by shaping the choice and specific arrangement of a way or path in the drawing. The student uses the tangible elements in his or her drawing as a source domain for the generation of meanings. He or she then relates them to the meanings of abstract objects, concepts or notions in the target domain, which is science. Finally, a web of mutual relations of meanings emerges between a concrete source domain and an abstract target domain. Without metaphorization, meanings related to the abstract target domain might be barely accessible or expressible by the student. Thus, metaphors are used by the students as tools for the creation, signification and communication of abstract and otherwise hardly accessible meanings. The model pictured in fig. 3 guides administration and analysis aiming at insights about students' beliefs about diachronic nature of science.

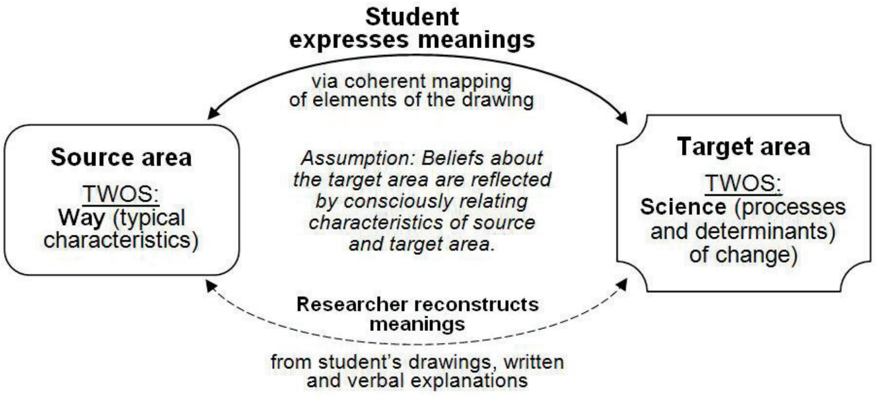

Fig. 3: Source-target model of intentional metaphorization.

Based on this model, some methodological criteria for the choice of appropriate metaphors can be established:

a) The source domain should be familiar to all students, culturally fair and developmentally as well as cognitively appropriate.
b) The source domain should be fruitful in order to enable multiple and varying relations between the two systems of meaning.
c) The students should not be too emotionally involved with the source domain, in order to prevent any bias carrying over to the target domain.

If students for instance were asked to draw scientific knowledge (target domain) as a building (source domain), the level of emotional involvement might be sufficient. If they were asked instead to draw scientific knowledge as a school building, then the source domain might lead to the production of emotions and ideas which will be transferred to the target domain without being sufficiently rooted there.

Analyses of metaphorical drawings are built upon the assumption that culturally shared metaphors expressed through drawings reflect the drawers' cognitive and emotional states (Berlin, Olson, Cano, & Engel, 1991). Although Lakoff (1993) and others provided cogent arguments supporting this assumption, the level of inference is rather high. Any valid interpretation of a metaphorical drawing requires that researchers and participants have access to the same pool of metaphors, which are rooted in the culture they both share.

3. ANALYSIS OF STUDENTS' DRAWINGS OF "THE WAY OF SCIENCE"

3.1 Sample and Procedure

The TWOS instrument was administered to 29 German middle school students at the age of 14-15, attending the 8th grade of a German "Gymnasium" (comparable to secondary school). Only 4 of the students were male. The participants took a significant part of their non-science classes in English ("bilingual classes") hinting at above average language abilities.

In order to validate the TWOS instrument two datasets were obtained from the same group of students. One data set was gathered before and one after an eight-week teaching intervention. The intervention was based on three different historical case studies[4] developed in the course of the HIPST-Project (Höttecke, Henke & Rieß, 2012) and presented to the students during their regular physics classes. Thus, the assumption was justified, that TWOS should indicate any change in students' ideas about the diachronic NOS. The teaching intervention distinguished itself by the following aspects:

- teaching and learning science with its history and philosophy
- experiments with replicas of historical instruments
- explicit-reflective learning opportunities on various aspects of NOS (Henke, Höttecke & Rieß, 2009)

Students had no previous experience with historically informed science teaching beyond those expected to be part of "traditional" science lessons (e.g. anecdotes or short outlines of scientists' biographies). It was ensured that the students' history classes did not refer explicitly to science or science related issues directly before the first and until the final administration of TWOS. Pre- and post-intervention data were analyzed independently in order to prevent mutual influence. Intervention effects were not part of the analysis. For later stages of the analysis (see below) datasets were merged and membership to pre- or post-dataset was anonymized.

Structure and administration of TWOS is straightforward. A short questionnaire is administered first. There the students were asked to draw their idea of "the way of science" in a blank space of given size, giving detailed written comments explaining their drawing on the next page. A second question focuses on students' epistemological beliefs, asking *if, how* and *why* scientific knowledge may change. Responses to this context-free question may expose possible inconsistencies between students' beliefs about the diachronic NOS and their beliefs about knowledge change in general.

Development and testing of various guiding statements for the drawings activity resulted in the following instruction: *"Think of science as a way, or trail, starting long ago. Please, draw this way!"* Trials with students of various age groups indicated several misunderstandings of this simple stimulus. The students then were drawing:

- a picture displaying a logical model of research activity without any relation to historical time, e.g. idea → experiment → result
- images of themselves as learners at school
- scientists, laboratories, lab materials indicating research work-in-progress
- simple "knowledge vs. time" diagrams

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

To ensure a better understanding of the activity as producing metaphors, we added a second stimulus: *"The way of science may be narrow or broad, steep or flat, even or uneven … or everything else that fits your ideas about the way of science through time"*.

After completing the questionnaire, a trained interviewer elicits in-depth explanation of the students' drawings, omitting guiding comments or direct questions. The second step focuses on clearing up the meaning of elements of the drawing not explained in the students' written and oral comments. The interviewer is instructed to use a restricted set of non-directive questions like *"What do you mean by …?"* or *"Could you please talk a bit more about …"*. The interviewer had to memorize and use a list of expressions expected to be used by the students during the interview (c.f. Carey *et al*., 1989). Whenever a student used words like "progress", "change", "problems", "success" or "influence", the interviewer had ask for clarification.

Since students tend to reproduce commonly held stereotypic views in a first drawing, but may show more elaborated views when asked for a second drawing (Finson, 2002), students are asked at the end of the interview, if they would 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 fact that the extended use of a single metaphor allowed for generating new insights (Evans & Evans, 1989).

TWOS data can be analyzed according to a general qualitative methodology as depicted in figure 4. The structure is inspired by Galili's and Hazan's (2001) framework for reconstructing students' conceptions about NOS. Although this procedure was developed for and in the context of TWOS it can be applied to other metaphor-based research efforts.

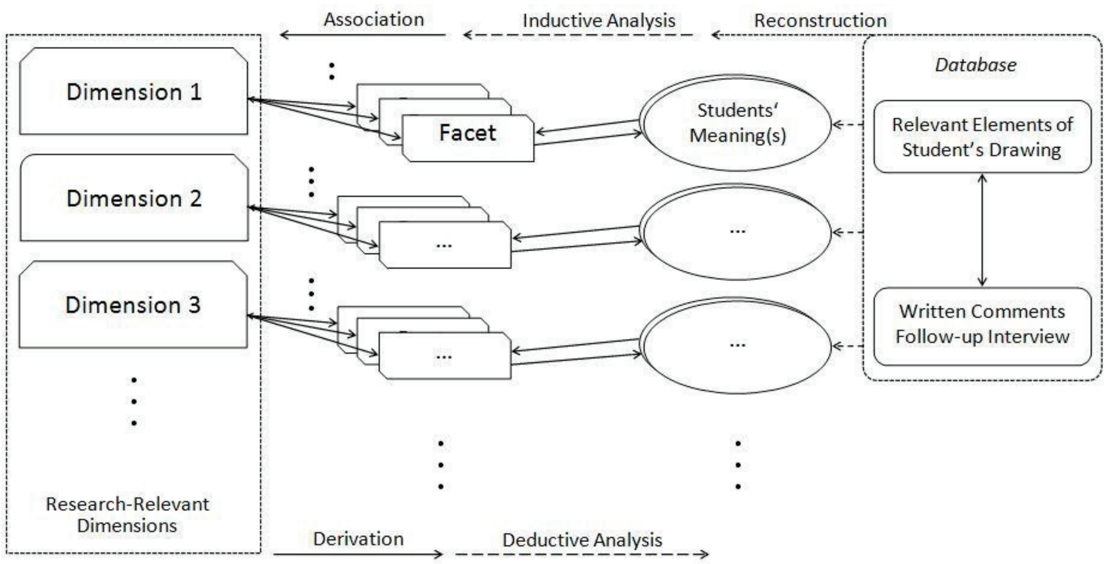

Fig. 4. Framework for inductive-deductive reconstruction of students' meanings.

3.2 Metaphor-Analysis

In a first step, researchers hermeneutically reconstruct the symbolic meanings of a student's metaphorical drawings (see fig. 3). Each element of the drawing will continually be interpreted and re-interpreted in isolation as well as in relation to each other. Valid and adequate reconstructions of students' ideas expressed through the drawings can only be established by the analysis of additional data sources which are written and/or oral explanations as well as follow-up interviews (Maxwell, 1992). The level of inference can be lowered, if general properties of the drawings like a colored background or the level of sophistication of a drawing will be excluded from data analysis. The analysis of a drawing focuses any element a student has addressed explicitly in their written explanations or during the follow-up interview.

Reconstruction has to take into account the contingency, context-dependency and everyday-character of any object in the drawing (stone, hills, lakes, road signs etc.). Each object used in a student's drawing is embedded in his or her broader conceptual metaphorical framework. A stone for instance might convey several different meanings, which depend on the structure and content of the drawing as a whole.

The result is an inventory of elements of a drawing, which contains the ideas about science signified by each element. This approach is similar to but more tangible than the inventories proposed by Lakoff and Johnson (1980). Table 1 illustrates the reconstruction of students' metaphors in TWOS on the basis of the drawing depicted in figure 2. The short paragraph in the upper line of table 1 presents paraphrased interview-data. The left column shows the inventory of metaphor-relevant elements of that drawing, the right shows the corresponding meanings inferred from on the students' explanations.

The use of an object like a stone in a drawing is highly idiosyncratic. In figure 2 the hills and stones for example signify obstacles occurring during research. Similar elements in another student's drawing might have been used to express alternative ideas like a high level of research activity or newly occurring research questions. During data analyses, any researcher has to take into account, that each element of a drawing might signify a multitude of ideas. The assignment of different meanings to the same element in a drawing is usually triggered by follow-up interviews, when students have the opportunity to relate a variety of ideas about science to the elements of their drawings. During an interview, the metaphorical meaning of an element may shift or multiply, if referred to from different angles.

Table 1: Inventory of metaphorical elements of a students' drawing of TWOS and their inferred meanings

Students' description of drawing (see fig. 2; condensed from written and oral explanations)	
Scientists of the past had to master typical problems of science. When approaching a difficulty on their research some of them decide to avoid this difficulty by following an easier path avoiding the question, while a single scientist decided to solve this problem once and for all. The other scientists do not behave like him leading to serious problems in their research afterwards. Close to our present, they choose to collaborate, since they decided to explore unknown territory. The way won't end, since they will get new solutions that lead to new questions.	
Elements	Reconstructed Meanings
path (single, structured)	science as research activity (collective experience of individual scientists)
hills/mountains (recurring)	externally inflicted obstacles (inadequate scientific instruments, procedures)
stones (on the path)	internally inflicted obstacles (lack of research experience)
lake (interrupting path)	research question/problem (difficult, posing itself)
crutch (splitting path)	scientists departing from collective enterprise (methodological decision)
circumventing the lake	research alternative (provides final answer to question, opportunistic, shallow)
passing the lake	research alternative (provides final answer to question, idealistic, deep)
path (narrow, separated)	individual scientist (resourceful, autonomous)
crutch (merging)	scientists cooperating (combining experiences and collective knowledge)
tunnel (dark, immersing path)	future research (no previous ideas, process and results unpredictable)
sun (shining on tunnel-exit)	solved research questions (adding to as well as replacing previous results)
points of ellipsis	scientific activity as depicted will go on indefinitely (successful problem-solving)

3.3 Qualitative Content Analysis

The second step of data analysis starts from a set of broad, theoretically derived dimensions. The dimensions should be capable of describing, categorizing and differentiating students' views about the diachronic nature of science.

1. Epistemological beliefs about changes in scientific knowledge and about its ontological character (Hofer, 2006; Priemer, 2006)
2. Beliefs about factors determining change and development in science (Borries; Angvik & Körber, 1997)
3. Narrative structures underlying students' descriptions and explanations of their way of science (Schreiber, 1999; Pandel, 2002)
4. Beliefs about the socio-epistemic structure of science (Driver; Leach; Millar & Scott, 1996, Longino, 2013) reflected in their metaphorization of scientific change

All dimensions were characterized and differentiated by its facets, which are suitable for indicating students' beliefs from a deductive and theory-driven perspective. Such facets might for instance represent different statements about scientific change. While the dimensions have framed and guided our research perspectives from the very beginning, the facets need to be adapted to the contingencies of students' meaning-making. This requirement led to choosing the methodology of qualitative content analysis, which, next to deductive classification of students' assertions, allowed for inductive generation of new, empirically relevant, facets (Mayring, 2010).

To give an example: The two facets of the dimension *epistemological beliefs,* "*scientific knowledge grows by recurring refutations/modifications of incorrect ideas*" and "*scientific knowledge grows continuously adding-up new and correct ideas*", were deduced from previous research. Two other facets, "*scientific ideas replace one another in a linear succession*" and "*competing scientific ideas exist in parallel over a period of time*" were developed inductively from the data.

Table 2 presents the dimensions of analysis and their facets in their final form, resulting from extensively piloting the TWOS instrument. Nevertheless, future studies using the TWOS procedure may add or modify the dimensions according to their specific research agendas and theoretical perspectives. The employed dimensions are described in a later section, where they are illustrated by a selection of students' responses.

Table 2: Dimensions of analyzing students' views about the diachronic NOS.

Dimension	Facets	Data sources
1. Epistemological beliefs	*knowledge accumulating (additive)* *knowledge accumulating (mending)*	drawings, written explanations, follow-up interviews, includes responses to additional context-free question: "knowledge change"
	refutation as basic mechanism (fruitful) *refutation as dead end (error)*	
Dynamics of knowledge change	*science characterized by competing ideas* *science as succession of ideas*	
Ontological character of knowledge	*science as uncovering nature's secrets* *science as inference for best explanation*	
	knowledge about nature is finite *knowledge about nature is boundless*	
	science can access true knowledge about nature *true knowledge about nature is inaccessible*	
	scientific knowledge as concepts, model & ideas *scientific knowledge as technological artifacts*	
2. Factors determining scientific change	*Factors, their type of influence, location on time-scale & evolution through time*	drawings, follow-up interviews
3. Narrative structure of scientific change	*Traditional, genetic, circular, teleological & organic patterns of "talking history"*	drawings, follow-up interviews
4. Metaphorization of scientific change	*science as collective entity* *science as evolving network*	drawings, written explanations, follow-up interviews

The trustworthiness of TWOS data analysis rests on three pillars:

(1) Theoretical relevance and applicability of perspectives for deductive classification
(2) Validity and internal generalizability of inductively derived facets
(3) Intersubjective reliability of meanings reconstructed from students' metaphors and classification of students' views to TWOS dimensions and facets

Regarding the validity of procedure and results of the study presented in this paper, aspects (1) & (2) of TWOS data analysis were negotiated between three researchers/experts in the field of NOS and students' beliefs as well as history education (two of them authors of this paper). Aspect (3) was ensured by independent classification of a sample of TWOS data and facets, resulting in good inter-coder agreement (for details, see Henke & Höttecke, 2013).

3.4 Construction of Ideal Types

Analysis of students' beliefs about the diachronic NOS has to meet conflicting requirements. On the one hand, the analysis strives for the identification of broad, stable, and inter-individual patterns of beliefs like scientism or progressivism. On the other hand, data analysis has to take into account that a student's meaning-making is based on his or her individual – sometimes even unique – preference for specific drawing-elements, symbols and their relation to each other. Research based on qualitative data is commonly challenged by this dilemma (Kelle, 2005). A method with a long track record in achieving dialectical agreement between the two opposing requirements is the construction of "ideal types" based on qualitative data analysis (Kluge, 2000). Solomon and her colleagues (1994), for instance, preferred such an approach has been, resulting in a typology of students' beliefs about the different roles of scientists.

Consequently, the final step of TWOS data analysis aims at constructing a typology of students' beliefs about the diachronic NOS. So-called "ideal types" provide heuristic tools for structuring processes of meaning-making and human behavior. An ideal-type presents a second-order construct based on previous results of data analysis by transforming individual beliefs, meanings and decisions into a selection of a few expressive, abstract categories (Hearn, 1975; Psathas, 2005; Weber, 2009). So far, the students' beliefs are expressed through individual assignment of various facets of theoretical dimensions. In the context of this study, an ideal-type therefore represents a holistic, empirically grounded and logically coherent combination of students' beliefs across all of the dimensions covered by TWOS, therefore providing a useful tool for an overall understanding of their perspectives on the diachronic NOS.

The process of reconstructing an ideal type from students' beliefs is best illustrated by the following example: The process starts with an individual student, who, for instance, uses a *genetic narrative structure* and tends to regard science as a *collective enterprise*. In the next step one identifies students with a similar pattern and investigates, if their ideas regarding other dimensions show some form of logical or empirical consistency. It appears that two further ideas resonate with the pre-established set of beliefs: Scientists are aiming at *disclosing nature's secrets* and thereby contributing to a *successively growing body of true scientific knowledge*. In the next step one might find that students holding either one or the other of these beliefs also tend to see change in science caused either by scientists struggling with *internal inadequacies of science* (e.g. inadequate instrumentation) or by *external obstacles* (e.g. lack of societal recognition). At this point one has to check and re-check the previous interpretations, in order to assure that these last findings really hint at the emergence of two distinct sets of beliefs about the diachronic NOS. If this is the case, the next round of reconstruction starts assuming the existence of these two ideal types.

Progressing in such a way, the number of sets of identified beliefs is continually growing. Although it may seem this way, the development of ideal types is not a result of a linear step-by-step procedure. Instead, this interpretative process is circular and iterative. An ideal-type is the result of a process that aims at maximizing *internal consistency* while at the same time maximizing its *external discrimination* against all other types already established from the same data set. An essential part of the transformation process relies on *emphasizing* and *idealizing* the types *beyond* the sheer representation of empirical tendencies. In this respect ideal-types differ from real- or proto-types. 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 presented further below.

All interpretations and idealizations were finally discussed in order to maximize agreement among researchers. Disagreement or inconsistencies were resolved either by revising of the internal belief-structure of an ideal-type, by changing its emphasis or by partially re-analyzing the underlying data.

4. RESULTS

In this section, selected results from an application of TWOS to the sample described above will be presented. Due to the idiosyncrasy of the elements of students' drawings used for symbolizing aspects of change in science, their views about the diachronic nature of science will be illustrated mainly through students' written explanations or transcripts[5] of interviews. The results are by no means exhaustive, but shall serve the purpose of illustrating the analytical fruitfulness of the TWOS instrument.

4.1 Epistemological beliefs and beliefs about the ontological character of scientific knowledge

This dimension represents two common aspects of NOS, students' epistemological beliefs about the development of scientific knowledge and students' beliefs about the ontological character of scientific knowledge (Carey & Smith, 1993; Schommer-Aikens, 2002).

About 80% of students use their way to express their ideas of change in science. If the students explain their drawings, most of them directly relate theoretical scientific knowledge to the entities of nature it explains. This behavior indicates an entity-realist position (Cartwright, 1983). Implicitly assuming a finite number of different natural entities, students express their belief in a finite, predetermined amount of scientific knowledge to be "found out" over the course of time. Oftentimes these students highlight significant scientific achievements in the past:

[5] Each passage was translated from German into English by the first author. Each code at the beginning of a passage indicates a certain student.

A6R5W: "[…] 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."

In accordance with Messick's (1989) statement that "One must be an ontological realist in order to be an epistemological fallibilist" (p. 26), many students who regard nature as directly accessible through science, also justify the supposedly never-ending knowledge generation of science by its self-propagating and self-correcting character:

A6E5W: "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 it was right before."

Most interestingly, the TWOS procedure allows for students to express time-frame dependent perspectives on the dynamics of knowledge change in science: 7% of the students in our study explicitly argue for the fact, that scientific knowledge got routinely refuted and/or replaced in the past, while contemporary knowledge now needs only minor adjustments with new insights being added. This shows a tendency for attaching different epistemological beliefs to contextually different types of scientific knowledge, which is a recurring theme throughout the data:

When explaining their *drawings* about 78% of the students present scientific knowledge as developing mainly cumulative (vs. 22% by refutations). In their responses to the additional, *context-free* interview question on knowledge change, however, this relation changes to 54% cumulative vs. 46% by refutations. It seems that in the context of this metaphorical, drawing-based assessment, students tend to show less adequate beliefs about the nature of scientific knowledge than in context-free assessments bearing no connection with history of and change in science.

4.2 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 and colleagues (1997) asked to rate a given set of factors according to their perceived potential for influencing the course of history. In TWOS the factors influencing change and development in science were inductively derived from data. Table 3 summarizes prominent results. For the sake of brevity only factors symbolized directly in the drawings and mentioned by more than 15% of all students are reported here. Also indicated are students' beliefs about the hindering or helping character of each factor as well as the location and evolution of its influence in time.

Table 3: Factors relevant for scientific change as expressed in students' drawings.

Factor	Location			Evolution	
Influence of …	past	present	enduring/ stable	rising	waning
Religion / Mysticism	UU	U	U	-	UU
Societal recognition of science	U	-	-	S	-
Experimental failures and problems	UU	-	-	-	U
Availability of technological artifacts	UU	-	S	SS	UU
Av. of advanced instruments / methods	U	S	S	SS	-
Building on previous knowledge	UU	SS	S	-	-
Specialization, emerging of disciplines	-	S	-	S	-
Great achievements	S	-	-	-	S
Curiosity as main motive	-	-	S	-	-

Type of influence: *helping* (S) *hindering* (U)
Relative frequency per row: *< 5%* (-) ≥ *15%* (S,U) ≥ *25%* (SS,UU)

In total, students view supportive factors as slightly dominating, regarding their influence on science as stable over time. According to their idea, the relevance of those factors, which have hindered the development of science in the past, is vanishing in the present. Supportive factors show the opposite, but less distinct trend. Their role is regarded as increasing from the past up to the present.

The types of factors and the character assigned to them indicate a mixture of chronological snobbery and presentism[6]. Students also tend to ignore, that features of contemporary science are *co*-produced along with social and cultural processes (Jasanoff, 2004). Another prominent view exposed by TWOS is students' technology-centered optimism regarding science. Similar to research about students' ideas on history in general (Borries, Angvik, & Körber, 1997), students in our study assume positive change in science to be indicated almost exclusively by the use, production and improvement of technological artifacts as tools and products of science. Ecological, ethical or social factors were neglected as indicators of change. On the other hand, students do indeed positively attribute ecological, ethical and social motives to scientific research (Driver et al., 1996). It seems therefore that students tend to evaluate the aims of science by different standards than its successes.

4.3 Narrative Structures

Due to the students' fragmented historical content knowledge their "talking history" in TWOS needs to be interpreted as a complex process of sense-making. They develop ad-hoc ideas on what and why something might have happened in the past, while keeping a steady

[6] *Chronological snobbery* refers to the fallacy of equaling "later" and "better" (Fischer, 1970; Barfield, 1967). In the context of TWOS, the notion of *presentism* refers to the fallacy of projecting features of contemporary science into the past. Students then base their explanations on the assumption, that those features were deliberately invented in the past and survived without any intermittent adaption.

footing in the present. Rüsen (1982) pointed out that these diachronic narratives about historical events from laypersons' and especially students' do not follow traditional paths of causality. Instead, the narrators try to construct a linear temporal sequence, afforded by a high amount of selectivity. Therefore, only include events appear in their narratives that link to other events already mentioned or to topics regarded as important based on implicit assumptions and attitudes (Schreiber et al., 2007). As a result, five basic types of narrative structures can be found underlying non-experts' narratives about history: *traditional*, *genetic*, *teleological*, *organic* and *circular* patterns (Pandel, 1995). The holistic nature of these patterns is captured by their graphical representations in figure 5.

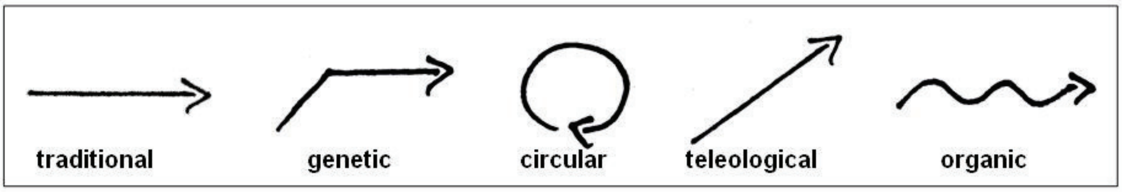

Fig. 5: Graphical representations of non-experts' narrative structures in talking about historical developments.

In TWOS, where students explain diachronic aspects of science, the sub-surface patterns of their narratives[7] therefore indicate their attitudes toward (past) science and reflect personal ontological and epistemological assumptions. During analysis, students' explanations are categorized according to the five types of narrative structures mentioned above, serving to expose associated ideas about the nature of scientific change.

It has to be noted, that there is no logical necessity for the students' drawings themselves to resemble the semiotic visualizations of fig. 5. Also, the students do not need to employ a single narrative structure consistently. Analysis instead shows that they express different ideas about the development of science by nesting and sequencing various narrative structures.

The following paragraphs illustrate each narrative structure occurring in our study with the most frequent ideas about science associated with it.

<u>Traditional:</u> Science is characterized by a lack of qualitative internal changes or factors influencing its course. Most students however do not wish to express the idea that research activity stops, stagnates or knowledge production ceases. Instead, they indicate that scientific activity did and will follow the same pattern over time. It has to be noted, that a small minority of these students' first referred to *school* science as being monotonous and, after clearing that up during the interview, did not essentially change their way to have it represent professional science. This supports the hypothesis, that students' negative (positive) attitudes

[7] The term "narrative" does not imply a specific type of text produced by students during data collection using a certain mode of narration. 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, exhibiting (e.g. causal) interdependence, internal coherence, relation to a common topic and chronological order (Stone, 1979). The students' drawings accompanied by their written explanations and interview transcripts provide the texts to be analyzed.

towards school science shape their views about the diachronic nature of science as monotonous (diverse).

Genetic: A genetic structure characterizes change in science as occurring only, if a certain threshold or barrier has been overcome.

A8E6W: "My drawing [see fig. 6] 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 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 gravel 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."

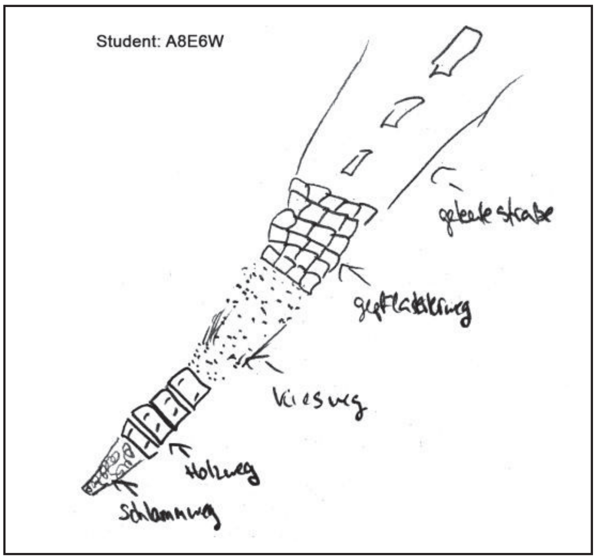

Fig. 6: Students' drawing coinciding with genetic narrative structure.

This student expresses the view that scientists had to confront external (nonscientific) criticism by sampling good evidence and thinking hard. There is no causality or teleology implied; the changes are only judged as necessary in retrospect. Overcoming a barrier leaves science with a good stock of exact conceptual knowledge and methods, enabling scientists to keep on working until science reaches another obstacle. According to a genetic narration science is maturing internally (evidence, arguments, methods), while reacting to external hindrances (disbelief, lack of support etc.).

Circular: This narrative structure focuses on the idea that historical development follows a circular pattern. Even if science is characterized by extensive qualitative changes and apparent progress, the final situation does somewhat resemble the starting point.

> *E6G6M: "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."*

In TWOS, this structure is mostly attributed to scientific change on a large scale. Students then are likening their ideas of the historical beginnings of science to the present.

Teleological: These narrations show a clear goal orientation of scientific change. The propositions of students in our study can be transformed into the form '…happened/changed, *in order to …*':

E7E6W: "Change will go on, since there is still not everything explained what happens in nature."

This narrative structure is characterized by a strictly teleological interpretation of scientists' actions: Change occurs due to scientists, who are pursuing goals either on s small scale (solving a practical problem at hand) or on a large scale (finalizing the existing body of knowledge):

A8N6W: "There will always be research and the knowledge will change again and again, since scientists try to find errors and fill out the gaps."

We could not observe any students, who alluded to any technological or ecological *telos.* This result is hardly surprising, since TWOS does not prompt the students directly to address the goals and motives for engaging in science. Thus, the students focused stronger on knowledge development in general and factors influencing scientific change.

Organic: This structure emphasizes recurring patterns in the history of science, highlighting students' ideas about the internal logic of "normal science". Figure 7 indicates, that students' drawings reflect this narrative structure pretty well. The patterns symbolize ups and downs in productivity, sequences of problem posing, problem solving and ingenious discoveries. They are regarded to occur in quasi-regular intervals. This internal logic is perceived as being natural and even law-like, although facilitated by scientists' participation.

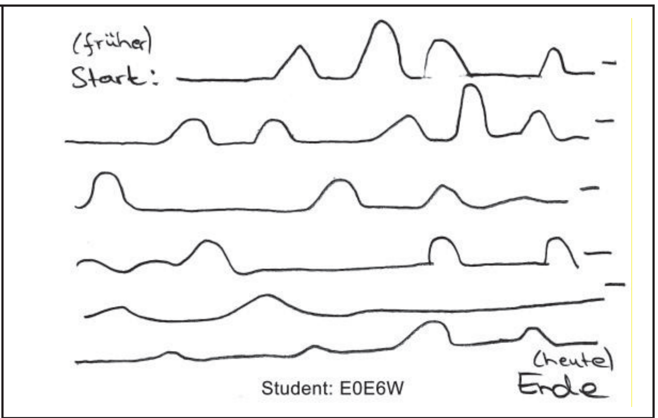

Fig. 7: Students' drawing reflecting an organic narrative structure.

4.4 Metaphorization

The dimension "metaphorization" captures a more or less consistent use of a set of elements in a student's drawing, which is in accordance with his or her views about the socio-epistemic structure of science. A consistent use of the metaphor "science as a way" means that students use certain elements in their drawings, which directly represent sets of beliefs about change of science in time. The source domain (way) then meets the target domain (time) quite directly.

Data analysis for this dimension is mainly inductive and starts from the inventories of metaphorical elements (see table 1) and students' written and oral explanations. Two distinct facets emerged and proved internally valid: (1) *science as collective entity* and (2) *science as an evolving network*.

The drawing in fig. 8 illustrates the first facet. According to this student's explanations, he sees science as a holistic activity, affected by external or internal perturbations as a whole. In this case students are drawing the development of science over time as a single line or path, not using elements like branches, crossings, dead ends or parallel tracks. Their views about science underestimate the role of concurrent research on similar topics, the existence of controversies and processes of internal differentiation (e.g. intermittent thematic collaboration, the development of sub-disciplines, communities and the like). There is no significant preference for a specific narrative structure. Still, these students stress the importance of external factors like religion/mysticism and technology. There is no effect of previous knowledge on theory development other than affecting the amount of research possible afterwards.

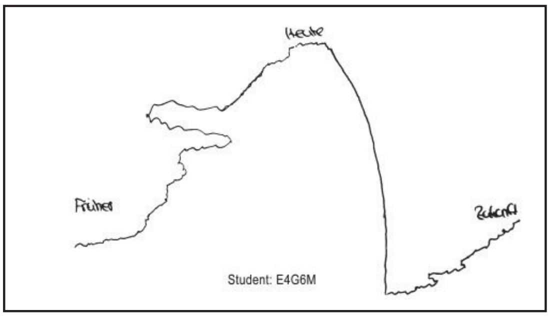

Fig. 8: Students' drawing illustrating science developing as sollective entity

The drawing in fig. 9 illustrates the second facet. According to this student's explanations, she sees science as a network of individual scientists as well as research groups, communicating and collaborating, grounding their own work upon the results of others or criticizing each other. Students like her have a tendency to favor a traditional narrative structure (see above), conveying the belief that these activities are typical and unlikely to change over time. This type of metaphorization involves a disregard for societal as well as religious influences, while influences due to individual failures and problems are a recurring topic in this kind of narrations. Nevertheless, there is no conclusive evidence that this metaphorization correlates with equating unsuccessful verification with failed research, reflecting a naïve verificationist view of science (Hodson, 1993).

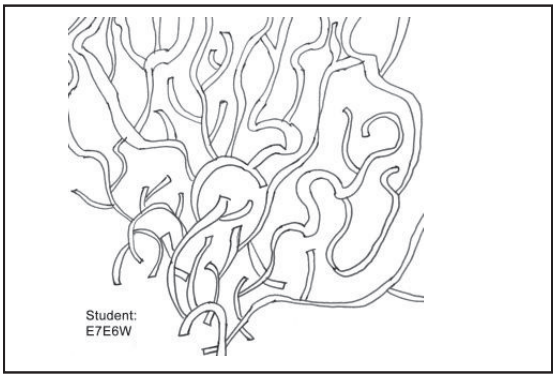

Fig. 9: Students' drawing illustrating science developing as evolving network

4.5 SYNTHESIS: THE VARIOUS WAYS OF SCIENCE

As already mentioned, the final result of an application of TWOS is a set of ideal-types sufficient to describe students' basic ideas about the change and development of science through time. Recurrent 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 validity of the resulting ideal-types, allowing for a moderate generalization beyond the specific sample of this study.

Table 4 presents a structured overview of the ideal-types reconstructed in our study. Brief descriptions clarify the idea about the diachronic NOS underlying each of the ideal types.

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

Type N°	*Change in science as ...*	Underlying view about the diachronic nature of science
1	*... mining a limited resource*	Scientists have been and still are successfully disclosing nature's secrets, providing true scientific knowledge with methods growing ever more effective. Due to a limited amount of still undisclosed natural phenomena, at some point in the future there might be nothing left to discover. Therefore, scientific activities as we know them are beginning to decrease und will have to terminate someday in the future.
2	*... finally growing up*	Science of the past overcame external, societal and technological obstacles (e.g. mysticism, religion, lack of acceptance, inadequate materials) suppressing the inherent potential of science. Extraordinary events or people (enlightenment, industrial revolution, genius scientists etc.) helped science break free from past constraints. Science today is mature, and therefore finally able to replace old and erroneous ideas of past science with the correct, true knowledge about nature.
3	*... Münchhausen-science*[1]	Science of the past was ridden with internal inadequacies (e.g. inadequate research instruments and strategies, hasty conclusions, lack of collaboration), preventing it from flourishing. Still, scientists produced or improved their tools for building knowledge (e.g. correct ideas to build upon, effective methods etc.), thereby pulling itself out of a problematic situation. Throughout the time, stability of scientific ideas depends on the tools scientists use, making todays ideas quite final.
4	*... a story of dead ends*	Science progresses evolutionary by sacrificing those who end up in blind alleys, whose research that did not manage to produce the results initially expected. They are clearing the way for those incidentally managing to ask the right questions or get the right ideas. Wisdom of hindsight leads to effectively identifying research bound to fail, successively minimizing the number of dead ends in science.
5	*... sequential problem solving*	Science produces knowledge effectively by solving problems successively one at time. Problems may arise from within science (e.g. conflicting evidence) or from the outside (e.g. stopping climate change), but have been and will always be solved with success. Each solution produced by scientific activity is unique and adds to the repertoire of scientific knowledge in a non-cumulative way.
6	*... objective technological progress*	As we can see with our own eyes, science improves successively by producing technological artifacts. There is no limit to the amount of this "knowledge" to be unveiled. Individual and societal needs determine the direction of scientific research and with it the types and solvability of its problems.
7	*... creative science towards techno-science*	Scientists of the past needed to work hard and creatively, since various obstacles (lack of technology, materials, rationality etc.) made successful research difficult. The role of creativity and ingenuity is declining with time, since nowadays technology takes over most activities in science, relieving scientist from most of the duties of the past, changing their role to managers of knowledge-production.

The typology highlights the fact, that some dimensions play a prominent role in shaping students' meaning-making about scientific change. The students’ narrative structures, for instance seem to emerge from and organize their epistemological and ontological beliefs. Also, students’ beliefs about factors influencing scientific change indicate their attitudes towards past science, which in turn play a major role in defining students’ views about the diachronic NOS on a more general level. Negative attitudes – e.g. seeing past science as problematic due to internal inadequacies – seem to evoke less adequate beliefs about social and epistemological features of science. More positive attitudes – e.g. stressing external obstacles – do not lead directly to adequate beliefs. Instead, these students’ show a weak tendency for strictly differentiating between past and contemporary science, stressing stable features.

The ideal types presented here will enhance our understanding of the belief-systems of “non-ideal” students by functioning as heuristic tools for analyzing their views about the diachronic NOS.

5. CONCLUSION

Students' beliefs about the diachronic NOS structure their meaning-making about past science. Teaching approaches based on the history of science like stories, case studies or historical-investigative approaches have to consider these preconditions in order to enable learning about NOS. Determining students’ beliefs on change and development in science and their influencing factors is an important step toward more informed teaching.

Analysis of students’ drawings and explanations of “The Way of Science” indicate that the metaphor-based drawing activity enriched by written and oral explanations and combined with a two-level data analysis provide a sound basis for reconstructing students’ beliefs about the diachronic NOS. The students in our sample neither expressed problems with understanding the activity nor with producing a wide array of way-metaphors. Since 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), it is currently not assured, if the TWOS-instrument can be used validly with students of various age groups. Thus, further research will be needed in order to test the validity of TWOS for a variety of different test-samples.

The TWOS procedure leads to a richer understanding of students’ beliefs, since it elicits ideas about change in science from a product- as well as a process-perspective: If students construct and explain their drawings students, they are make use of two different und sometimes conflicting conceptualizations of science - “science as knowledge” and “science as activity”. The procedure also allows for the expression of beliefs about epistemological, social and methodological features of science in a common context. This prevents the problems typically arising from artificially separating and spreading these issues over several questions and contexts. TWOS may therefore serve as a starting point for further investigations on the diachronic NOS. The typology of students’ views about change in science can also guide classrooms activities by enriching explicit philosophical reflections about the nature of change in science.

We are aware that the number and character of dimensions informing TWOS are quite specific and might have to be extended for future use of TWOS. Still, our results indicate, that students' beliefs about the diachronic NOS build upon more general beliefs about history and past science and are shaped by emotional undercurrents stemming from students attitudes about (past) science as well as science teaching. The ideal-types presented in our study reflect this interrelation.

TWOS data supports the hypothesis, that students do indeed differentiate between the nature of past and contemporary science on different levels, focusing mainly on methodological transitions and on the changing epistemological status of its knowledge. Based on the evidence presented by this study, it is plausible to assume that other dimensions of beliefs about NOS might also be affected by the time-frame within which they are assessed by students. Their ideas on tentativeness in science, for instance, might change with either past or present science as a point of reference. This knowledge can guide selection and reflection of historical and contemporary episodes of science in science lessons to enable learning about features of science in the context of their development and help to foster a critical stance towards proposals of scientific universals.

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