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Teaching Nature of Scientific Inquiry in Chemistry: How do German chemistry teachers use labwork to teach NOSI?

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Learning about scientific inquiry (SI) is an important aspect of scientific literacy and there is a solid international consensus of what should be learned about it. Learning about SI comprises both the doing of science (process) and knowledge about the nature of scientific inquiry (NOSI). German reform documents promote inquiry generally but do not equally address these two sides of inquiry. This study explores how teachers incorporate learning about SI into laboratory work in the Chemistry classroom. Semi-structured interviews were conducted with 14 secondary school Chemistry teachers (8 of them holding a Ph.D. in Chemistry) from Germany. The results indicate that teaching NOSI is not a primary goal for teachers. Still, some aspects of NOSI seem to be more easily incorporated in the Chemistry classroom, for example, critical testing and hypothesis and prediction. Teachers state 2 main criteria to identify suitable chemical laboratory work for teaching NOSI: adaptable parameters and low level of required content knowledge. Surprisingly, differences can be found between Ph.D. and non-Ph.D. teachers' views on teaching inquiry. The findings of this study can be used to (a) select opportunities for targeted research on teaching NOSI in the Chemistry classroom, (b) inform curriculum material development and (c) give impetus to science teacher education and professional development.

Keywords: *Nature of scientific inquiry; Laboratory work; Chemistry education; Teacher actions; Qualitative content analysis; Germany*

Introduction and Rationale

Knowledge about nature of scientific inquiry (NOSI) can help students to bridge the gap between science literacy (learning science) and scientific literacy (participating in

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*Corresponding author. Chemistry Education, Ruhr-University Bochum, Bochum, Germany. Email: christian.strippel@rub.de science-related discourses) (Roberts & Bybee, 2014). It provides students with a framework to better understand the limitations of scientific knowledge production and, thus, allows them to judge scientific information and participate in decision-making on science-related issues (Flick & Lederman, 2006, p. xii).

Reform documents in different countries as well as international science assessment studies have stressed the role of inquiry in science education for more than a decade (Achieve, Inc., 2013; AQA, 2013; National Research Council [NRC], 2000, 2012; Organization for Economic Co-operation and Development, 2006; Ständige Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland [KMK], 2005). This normative push can be considered as positive development in science education. However, Crawford (2014) states: '[l]earning *about* scientific inquiry involves both the "doing" (practices) of inquiry and learning *about* the "nature of scientific inquiry" as content' (p. 517, original emphases). This evokes the question whether the current push for inquiry is equally promoting these two sides of inquiry. In Germany, major efforts have been made to model and measure students' inquiry and NOSI competence (Neumann, 2011; Wellnitz, Fischer, Kauertz, Neumann, & Pant, 2012). However, the question of how knowledge about NOSI is being taught has so far not been addressed. This study sets out to examine how German Chemistry teachers connect the doing of inquiry during labwork and the teaching about NOSI.

Literature and Theoretical Framework

NOSI as a Framework for Learning

NOSI has been established as a framework for learning which is distinct from knowledge of SI as well as from nature of science (NOS) (Lederman et al., 2014; NRC, 1996; Neumann, 2011; Schwartz, Lederman, & Lederman, 2008). Although NOSI, SI and NOS are interrelated, they must not be conflated with each other (Lederman, 2006; Lederman et al., 2014). NOSI 'corresponds to a sort of meta-knowledge on the process of inquiry, including its conditions' (Neumann, 2011, p. 23). This includes knowledge about specific characteristics of the SI process, for example, the function of a specific investigation design (Lederman et al., 2014). SI, in contrast, refers to 'the ability to conduct scientific inquiry' (Neumann, 2011, p. 23), to the 'doing of science' (Flick & Lederman, 2006, p. ix). SI comprises 'the processes of how scientists do their work and how the resulting scientific knowledge is generated' (Lederman et al., 2014, p. 66). Finally, NOS 'typically refers to the epistemology of science, science as a way of knowing or the values and beliefs inherent to scientific knowledge and its development' (Lederman, 2007, p. 833). This means it is concerned with 'the characteristics of the knowledge as directly derived from how the knowledge is produced' (Flick & Lederman, 2006, p. xii). This can also include social, historical, philosophical and psychological aspects of science (McComas & Olson, 1998).

NOSI serves as a framework of learning objectives in this study because its contents are an important part of scientific literacy. There is good consensus on the contents of NOSI. Osborne, Collins, Ratcliffe, Millar, and Duschl (2003) identified 12 broad objectives for teaching about the 'Methods of Science' in a Delphi study. Six of these 12 objectives were rated as highly important and reached stable consensus amongst experts. Schwartz et al. (2008) also identified key NOSI aspects building mainly on the National Research Council publication about inquiry (NRC, 2000). Lederman et al. (2014) present a list of eight SI aspects as the basis for their Views-about-scientific-inquiry (VASI) questionnaire based on several science standards documents (Achieve, Inc., 2013; NRC, 2000, 2012). All three publications agree insofar as the aspects presented refer to the same stages of the research cycle: research questions, design, data collection, data analysis, and interpretation. The overlap between the three groups' aspects is shown in Table 1. Osborne et al. (2003) additionally identify 'creativity' as an aspect of scientific methods, while Lederman (2007) subsumes this under NOS.

We decided to use the list presented by Osborne et al. (2003) as the basis for the research conducted in this study because it has a solid theoretical and empirical basis and is widely cited in the educational research community. Schwartz et al. (2008)'s list, though an important contribution, does not represent NOSI on a broad enough basis. Finally, the VASI list was not yet available at the time of this study. Osborne et al. (2003)'s consensus NOSI objectives were initially used to analyze the German chemistry education standards and they also provided the basis for data collection and analysis.

The Context for NOSI Education in Germany

Science standard documents in Germany so far provide a fragile, yet potentially useful, foundation for teaching NOSI. Science education for the 11–16 age range is currently based on the federal *KMK Bildungsstandards*, which have been implemented into state curricula (KMK, 2005). The standard area *Erkenntnisgewinnung* ('inquiry') in the *KMK Bildungsstandards* for Chemistry[1] can be linked to the consensus NOSI learning objectives (Table 2). The standards address all the important steps of inquiry (question, planning design, collecting data, interpreting data). However, all these links between NOSI and the standards follow the same pattern: the standard statements aim for skills and practices while the NOSI statements aim for meta-cognition. For example, while the standards demand that students 'recognize and develop questions that can be answered using chemical knowledge and investigations' (KMK, 2005, p. 12), NOSI statements ask students to know that 'an important aspect of the work of a scientist is the continual and cyclical process of asking questions and seeking answers' (Osborne et al., 2003, p. 703). The 17–18 Chemistry curriculum for North Rhine-Westphalia[2] (NRW) presents a slightly different picture. While individual statements seem to aim more toward meta-cognition, the breadth of statements with links to NOSI is reduced (Table 2). The analyses of both documents suggest three potential implications: (a) learning of doing SI is intended but learning about NOSI is not; (b) standard developers assume that in conducting scientific inquiries students will implicitly learn about NOSI; (c) standard developers rely on curriculum materials and teachers to bridge this gap. For the latter, it has been shown that

Table 1. Aspects of the NOSI framework according to Lederman et al. (2014), Osborne et al. (2003) and Schwartz et al. (2008)

Osborne et al. (2003)	Schwartz et al. (2008)	Lederman et al. (2014)
Science and questioning: continual and cyclical process of asking questions and seeking answers, which then lead to new questions; new scientific theories and techniques	Scientific questions guide investigations	• Scientific investigations all begin with a question and do not necessarily test a hypothesis • Inquiry procedures are guided by the question asked
Diversity of scientific methods: science uses a range of methods and approaches; no one scientific method or approach	Multiple methods of scientific investigations	There is no single set or sequence of steps followed in all investigations
Scientific method and critical testing: science uses the experimental method to test ideas; there are basic techniques such as controls; outcome of a single experiment is rarely sufficient to establish a knowledge claim	Not addressed	Not addressed
Observation and measurement: observation and measurement are core activities of scientists; subject to some uncertainty but there may be ways of increasing our confidence in a measurement (not one of the original six important aspects)	Not addressed	All scientists performing the same procedures may not get the same results
Analysis and interpretation of data: science involves skillful analysis and interpretation of data; process of interpretation and theory-building that can require sophisticated skills; scientists can legitimately come to different interpretations of the same data, and therefore to disagree	• Justification of knowledge claims • Recognition and handling of anomalous data • Distinction between data and evidence	• Inquiry procedures can influence results • Scientific data are not the same as scientific evidence • Research conclusions must be consistent with the data collected
Hypothesis and prediction: scientists develop hypotheses and predictions about natural phenomena; essential process for the development of new knowledge claims		Explanations are developed from a combination of collected data and what is already known
Creativity: science involves creativity and imagination as much as many other human activities; some scientific ideas are enormous intellectual achievements; scientists are passionate and involved humans whose work relies on inspiration and imagination	Not addressed	Not addressed

(*Continued*)

Table 1. Continued

Osborne et al. (2003)	Schwartz et al. (2008)	Lederman et al. (2014)
Not addressed	Science as a community of practice	Not addressed
Not addressed	Multiple purposes of scientific investigations	Not addressed

enactment of the curriculum depends heavily on the individual teachers and their environments (Ball & Cohen, 2014; Fogleman, McNeill, & Krajcik, 2011; McNeill, 2009; Schneider & Krajcik, 2002; Squire, MaKinster, Barnett, Luehmann, & Barab, 2003). In fact, all three possibilities highlight the role of the teacher for creating opportunities to learn about NOSI and, thus, the importance to enquire into teachers' practices.

When regarding the teachers' crucial role in bridging the gap between standards and their classroom, two peculiarities of German science teacher education might exert further influence. Firstly, only a few instructional methods have been taught continually to teachers. One of these instructional methods is the *Forschend-entwickelndes Unterrichtsverfahren* ('researching-developing instructional method') that has influenced teacher training for almost 40 years (Schmidkunz & Lindemann, 1992). It suggests an idealized scientific investigation (problem posing, solution strategy, practical investigation) intertwined with pedagogical and instructional measures. This could also suggest that there is such a thing as a single scientific method. Secondly, there are two main routes to science teaching in Germany. Normal teachers qualify through a two-year master's program in education and a consecutive one-and-a-half to two-year placement in a school during which they also visit a teacher seminar. Individuals who already hold a Ph.D. in science are trained on the job and supported through teacher seminars. Thus, Ph.D. teachers receive significantly less theoretical input on teaching. The potential influence of this difference will be explored in this study.

The Potential of Chemical Laboratory Work for NOSI Teaching

Teaching NOSI requires examples. Labwork is a fundamental constituent of the science classroom and it offers great potential for teaching NOSI. In research as well as in science teaching, laboratory work has a central role in inquiry. Fundamentally, laboratory work consists of processes that have been initiated deliberately for the purpose of observation and/or measurement (Hinkelmann & Kempthorne, 2008, p. 21). The science of chemistry has developed a variety of ways to initiate and observe chemical processes in the laboratory—these are the chemical procedures (Sommer, 2007). In this study, we use the term chemical procedure when referring to a specific chemical process during labwork. This investigation is mainly concerned

Table 2. NOSI aspects and German Chemistry standards

NOSI aspects	11–16 standards (E = scientific inquiry; B = evaluation; ‘Students should … ’)	17–18 curriculum
Science and questioning	E1: recognize and develop questions that can be answered using chemical knowledge and investigations, particularly using experiments B4: develop up-to-date questions with connections to everyday phenomena which can be answered using chemical knowledge	Not addressed
Diversity of scientific methods	E7: use appropriate models (e.g. models of the atom, the period table of elements) in order to solve chemical questions	Not addressed
Scientific method and critical testing	E3: carry out qualitative and simple quantitative experiments and other investigations and write lab reports on them	The experiment allows to understand and practice the process of SI
Observation and measurement	E5: collect data from investigations, particularly experiments, or research them	Not addressed
Analysis and interpretation of data	E6: identify trends, structures and relationships in their own or research data, explain these and draw conclusions	Making your own analysis of experiments helps to develop problem-solving skills and problem-solving strategies
Hypothesis and prediction	E2: plan suitable investigations to test predictions and hypotheses	It is necessary to show and use appropriate examples from Chemistry of how to develop and test hypotheses and how these must be linked with the experiment as part of the process of SI
Creativity	Not addressed	Not addressed

with chemical procedures relevant for labwork in the classroom, that is, everything from a simple gas test to the preparation of organic esters to Vis-spectroscopy measurements. Here, it is important to be aware that using a chemical laboratory procedure only becomes part of the SI process, when it is embedded in a problem-solving strategy for a scientific question. However, it is unclear how much of this potential is currently realized in the classroom.

The literature offers a two-sided picture. On the one hand, science teachers state that epistemological goals such as understanding inquiry and practicing methods of scientific thinking are highly important during labwork (Lunetta, Hofstein, &

Clough, 2007; Séré, 2002; Welzel et al., 1998). On the other hand, it seems that the procedural and epistemological dimension of learning from labwork are often not realized in the classroom (Abrahams & Millar, 2008; Hofstein & Kind, 2012; Welzel et al., 1998). The procedural dimension of labwork is also often not realized in educative materials such as laboratory instructions. They seem to foster the idea of repeating a recipe instead of encouraging inquiry (Hofstein & Kind, 2012; Metzger & Sommer, 2010). This discrepancy between programmatic drive of teaching about NOSI through labwork and its apparent absence from the classroom leads to the research requirement 'in what ways the science laboratory can help to provide students with such understanding' (Hofstein & Kind, 2012, p. 195).

It is the aim of this study to investigate what concrete ideas teachers have about realizing the teaching about NOSI through labwork in the chemistry classroom.

Summary

In summary, NOSI can be treated as a distinct framework in education research. It entails knowledge about the various aspects of the process of SI. Links can be established between a NOSI framework and German Chemistry standard documents. At the 11–16 stage, these links are more frequent but the standard document remains on the skills and practices level. At the 17–18 stage, the standard document makes fewer references to SI but these statements aim more toward meta-cognition. Research on labwork in the classroom suggests that it offers great potential for teaching NOSI but this potential has so far not been widely realized. If it is realized in the German Chemistry classroom, this will rely on the Chemistry teachers' NOSI knowledge, awareness and willingness to create NOSI learning objectives for their students. For all these reasons, it is necessary to enquire into individual teachers' practice to create a description of the state of NOSI teaching in Germany. Our aim was to explore in how far teaching NOSI is already or could potentially be included into existing classroom laboratory practices.

This lead to the following research questions:

- What goals do chemistry teachers have when they use laboratory work in the Chemistry classroom?
- Which chemical procedures do chemistry teachers find most suitable to teach different NOSI aspects through labwork?
- What are general criteria that make chemical laboratory procedures suitable for teaching NOSI?

Methodology

Sample

In this study, we approached teachers who had completed their teacher training and had been working as chemistry teachers for at least two years. For the reasons described above, potential participants were recruited from two a priori groups: chemistry teachers who held a Ph.D. in Chemistry and chemistry teachers who did not hold a Ph.D. Our sampling strategy was guided by the decision to recruit participants from these two groups and by the intention that the participants from each group should have the same formal training but not all from the same training institutions. Teachers were approached and recruited from both comprehensive schools and selective schools (the German 'Gymnasium'). Other types of schools were excluded as they do not teach across the 11–18 age range. To avoid the bias inherent in only approaching first-degree contacts, a range of chemistry teachers was approached for participation. Teachers were identified via first- and second-degree contacts of the researchers and through a snowball process. Participants were also sought out using a government register for teachers. We were able to recruit a total of 14 participants (8 males; 6 females; MEAN (age) = 39.14 years; MIN (age) = 28 years; MAX (age) = 52 years; MEAN (teaching experience [t.e.]) = 5.63 years; MIN (t.e.) = 2 years; MAX (t.e.) = 16 years). Eight chemistry teachers held a Ph.D. in Chemistry (3 females; 5 males; MEAN (research experience [r.e.]) = 10.25 years; MIN (r.e.) = 3 years; MAX (r.e.) = 20 years) and six chemistry teachers did not hold a Ph.D. (3 males; 3 females).

Data Collection

To investigate the research questions, interviews were conducted with the Chemistry teachers. These interviews aimed to explore the teachers' implementation of labwork in their teaching practice with special regard to the NOSI framework. This approach seemed suitable as semi-structured interviews can be used to acquire rich information within one session (Bernard, 2006, p. 212). The interview protocol (Supplementary Material) in this study was designed to lead the teachers from an open discussion of the chemical labwork they use in their teaching to a detailed discussion of the relation between the NOSI framework and their own practice. At the beginning of the interview, socio-demographic information was obtained from the teachers. The main part of the interview proceeded through four phases: (1) the teachers use of labwork in the classroom and their goals with regard to these, (2) the teachers views on the relationship of chemical labwork and SI, (3) NOS and NOSI as frameworks informing chemistry teaching, (4) chemical labwork as examples to illustrate aspects of NOSI. Consensus aspects for NOS (Lederman, 2007) and NOSI (Osborne et al., 2003) were used as input in stages three (NOS and NOSI) and four (NOSI) of the interview (Supplementary Material). The teachers' discussion of NOS is not the focus of this article. The interview protocol was pilot tested with three secondary science teachers individually and adjustments were made to the phrasing of questions and prompts. These three interviews were not used in the analysis presented here.

All 14 interviews presented here were conducted between May and July 2013. The interviews were conducted by the first author in a face-to-face situation. The interviewer visited most participants at their workplace, while some also visited the interviewer at university. The interview was always conducted in a room exclusively used by the interviewer and the participant. Individual interviews lasted between 20 and

50 minutes with most interviews lasting between 30 and 45 minutes. All interviews were recorded digitally and transcribed using *F5* transcription software.

Data Analysis

We analyzed our data using qualitative content analysis (Mayring, 2014). As a first step, all interviews were transcribed. In the next step, the texts were coded using *QCAmap* software. Research question one (teachers' goals when using labwork in the Chemistry classroom) was addressed through inductive coding of the interviews (Table 3). It was decided to use inductive coding on question one because we also wanted to include goals that might not directly address the learner. As will be shown in the results section, this allowed us to identify a set of goals that had not been described in the literature. The analysis of the teachers' goals was restricted to the part of the interview before the introduction of the NOSI framework. The latter part of the interview was omitted from analysis for this question as statements regarding their goals might have been given by the teachers to accommodate the perceived intentions of the interviewer. For both research questions two and three, the whole interview was used for analysis. Research question two was addressed by a deductive coding strategy using a priori codes (Table 4). The codes were generated from the NOSI aspects described in the literature (Osborne et al., 2003). Here, initial coding was used to determine whether appropriate statements falling under each of these codes could be found in the texts (Table 4). Research question three (criteria identifying suitable chemical labwork for teaching NOSI) was again addressed through inductive coding (Table 5). The literature so far only suggests criteria for school labwork in general (e.g. health and safety, probability of success). As no such criteria have been described with regard to teaching NOSI through labwork, inductive coding seemed suitable.

These coding strategies were initially carried out on four (i.e. more than 10%) interviews selected from the different groups of interview partners. The codings were checked for inter-coder agreement (ICA) by two independent coders (Mayring, 2014). Acceptable ICAs could be established for all three categories (ICA (Goals) = 0.89; ICA (Criteria) = 0.82; ICA (labwork for NOSI = 0.91) as values over 0.80 are considered good for categories with multiple coding options (Miles & Huberman, 1994, p. 64). Disagreements were discussed and ultimately decided on by the first author. After all categories had been established and tested, all interviews were analyzed by the first author.

The coded transcripts were then used to create aggregate descriptions of the teachers' views within each category. To address research questions one (goals) and three (criteria), the codes were summarized into broader categories (Tables 3–5). For example, the codes that students should know (1), be able to perform (2) and be able to adapt (3) a chemical procedure were subsumed under the category of 'learning practical skills'. Research question two (choice of chemical labwork) was addressed analyzing the respective codes in a twofold way. On the one hand, we held the NOSI aspects constant and analyzed which chemical labwork was used to teach them. On the other hand, we held the most prominent chemical labwork constant and analyzed for which NOSI aspects it was used (Table 6).

Table 3. Inductive codes addressing Chemistry teachers' goals for labwork (T = teacher; PT = teacher holding Ph.D.; *N* is the number of individual teachers stating this aim out of 14 teachers)

Inductive codes	Anchor examples	Main categories
Students should learn the scientific method (*N* = 10)	I want to convey the experimental method as a way of testing certain phenomena (T5) A chemist should rely on the experiment. […] I emphasize that as often as possible in the lab	Learning scientific thinking (*N* = 13)
Students should learn to think scientifically (*N* = 7)	Students should learn to show a scientific way of thinking (PT7)	
Students should learn to choose a chemical procedure in order to answer a scientific question (*N* = 6)	How do I show that I have done the right thing? If you want to prove something, you have to show that your inquiry was suitable (PT3) You have a number of bottles. Which substances do they contain? Students can decide to determine the density or the melting point or the reactivity (PT4) Students should choose a method that helps answer their question and produce knowledge (PT5)	
Students should learn about a chemical procedure (*N* = 7)	It is important that it becomes transparent for the students how a chemical procedure works (T1) In an experiment, it is important that the students know […] all the different steps of a procedure (PT2)	Learning practical skills (*N* = 14)
Students should be able to perform a chemical procedure (*N* = 5)	I find it very important that during an experiment the students can do everything on their own (PT1) I think it is important that students can do the detonating gas test […] but also know how to use physical procedures like measuring small portions of substances (PT6)	
Students should learn to adapt a certain procedure (*N* = 3)	We tried to react copper oxide and charcoal. […] It did not work for most of the class, when they simply mixed the substances. So, I wanted them to try different ratios to gain copper from copper oxide (L5)	

(*Continued*)

Table 3. Continued

Inductive codes	Anchor examples	Main categories
Teacher wants to offer his students a cognitive anchor for the conceptual chemical knowledge to be learned (*N* = 8)	To show how simple it is to support what they know theoretically with an effect that will help them to keep the knowledge in their heads (PT7)	Teaching goals (*N* = 12)
Teacher wants to create an everyday context (*N* = 5)	I use for example titration to show how different substances influence the pH-value of everyday substances, for example lime in egg shells, teeth, shells (T2)	
Teacher wants to comply with the curriculum (*N* = 4)	I use everything that complies with the curriculum (T6)	
Teacher wants to work cost- and/or time-efficient (*N* = 2)	If you look at the repertoire of chemical synthesis, you have to decide which one is the easiest and which one uses the cheapest chemicals (PT8)	

Results

The results present the categorical analysis for all teachers' statements. We use individual teacher's statements to illustrate these findings. Where individual teachers' statements are given, these have been translated carefully from the German original. We use abbreviations to indicate whether the statement was given by a teacher without a Ph.D. (T) or with a Ph.D. in Chemistry (PT). The numbers identify individual teachers.

Teachers' Goals When Using Labwork in the Chemistry Classroom

The teachers state a range of goals that guide them when using labwork in the Chemistry classroom. Through discussion between the authors and consideration of the literature, three broader groups of goals emerged (Table 3): 'learning scientific thinking' (Thinking), 'learning practical skills' (Skills) and 'teaching goals' (Teaching).

The 'Thinking' category contains codes that aim at students' procedural knowledge. It was addressed by 13 teachers (Table 3). Most prominent in this category (10/14) was the statement that students should learn how to use the scientific method:

> Generally the scientific method itself, defining a question and a problem […], design an experiment accordingly and separate strictly between observation and interpretation when I am carrying out the procedure. (PT6)

The core message for the teachers seems that there is the scientific method and that it involves an experimental design. Other teachers phrase it differently but reiterate the emphasis on the experimental design. Seven teachers state that they want their students to learn how to think scientifically when using labwork. They aim at different aspects of that process:

Table 4. Deductive codes addressing 'Chemical labwork for NOSI' (*T* = teacher; PT = teacher holding Ph.D.)

Code (labwork that is useful to facilitate learning about …)	Anchor examples
Science and questioning	If you burn a piece of charcoal, the students know from their everyday experience that only ash will remain and that this will be lighter. […] If we burn the iron wool, we get an increase in mass. That seems strange. And then we have to develop new questions. And then you do new experiments, like burning matches when you have sealed the test tube (T1) Science and questions means in principle that you might go through the same process again and again. […] For example, when you simply heat copper oxide and activated carbon and then you continue to develop that (T5)
Diversity of scientific methods	I am thinking about a Fehling reaction. That is relatively simple to do, simple to observe and simple to come to a conclusion. […] On the other hand, I could use MS or NMR which is a lot more complex (PT5) You can use different indicators, different acids and bases to get to the right results (PT7)
Scientific method and critical testing	You can look at thin-layer chromatography for example. If you use reference substances you can identify what is in a certain mixture (T1) How can you show that an alkane contains hydrogen and carbon? It is not enough to do a positive test, you also have to conduct a negative test and show that other [elements] are not in there. […] You make a total oxidation and then you do test with lime water and test for water. But you have to talk about the order. Where does the water really come from? (T4)
Observation and measurement	Observation and measurement are key. But it does not always have to be quantitative in Chemistry. Often you want to see the type of reaction, for example the production of gas (PT6)
Analysis and interpretation of data	Analysis, interpretation of data works at different stages, for example […] law of conservation of mass. For example the classical experiment with matches in a test tube, seal it with a balloon, weigh it before and after. Typically not all eight groups get the same results, so you have to start talking about data (T4)
Hypothesis and prediction	Hypothesis and prediction is a standard thing in the classroom. You let the students come up with a prediction before you start the experiment. […] Burning of iron wool is a classic. Is it lighter, heavier or the same? (PT4)
Creativity	You need creativity everywhere. […] For example, when you set up the apparatus. You can give students various pieces of apparatus and they need to improvise. They can come up with a preliminary apparatus for distillation (T3)

Table 5. Inductive codes addressing Chemistry teachers' criteria for using labwork in teaching NOSI (T = teacher; PT = teacher holding Ph.D.; N is the number of individual teachers stating this aim out of 14 teachers)

Inductive codes	Anchor examples	Main categories
Chemical procedure should have adjustable parameters ($N = 9$)	If the students do not just use the chemical procedure like a recipe […], then they can get a lot more out of it. (T1) Students often do not know that you have to control parameters because student experiments are designed to be fool-proof (PT3)	Criteria specifically addressing requirements for teaching about NOSI ($N = 12$)
Students should be able to understand the procedure with a limited amount of chemical content knowledge ($N = 9$)	It is not always possible to do the things you want to do with the students because they require too much content knowledge. (T6) [If the procedure] is relatively simple, then it is relatively simple to observe and then you can make an interpretation relatively easily and you do not need a huge amount of content knowledge (PT5)	
Chemical procedure should be time-efficient ($N = 6$)	It works in principle but time is a limiting factor (PT3)	
Chemical procedure should produce strong effects ($N = 4$)	A lot of things cannot be used to teach about scientific inquiry […] because you cannot really see what is happening (PT5)	
Chemical procedure should require limited apparatus ($N = 3$)	I am sure you can achieve a lot of that […] but using so much material, I do not like that very often (PT3)	Criteria addressing general requirements for the use of chemical procedures in the classroom ($N = 7$)
Chemical procedure should relate to the curriculum content ($N = 3$)	You need a procedure that is also in line with the [curriculum] content (T6)	
Chemical procedure should be in line with safety regulations ($N = 2$)	You need to make sure that you comply with safety regulations in any of these instruments (T1)	

> I want to convey logical thinking in a way. […] Get the important information out of an experiment through observation and measurement, make the right conclusions. (T3)

This displays the teachers' aim to improve the students' doing of inquiry in terms of the thinking involved. Though, it remains unclear in how far, for example, finding

Table 6. Chemical labwork suitable to illustrate NOSI objectives (*N* is the number of individual teachers stating this procedure out of 14 teachers)

Chemical procedures	Laboratory techniques stated by the teachers	NOSI aspects mainly associated with these procedures
Test reactions ($N = 7$)	Oxygen test with glowing splint, hydrogen test with burning splint, carbon dioxide test with lime water, glucose test with Fehling agent, nitrite test with test kit	Scientific method and critical testing
Titration ($N = 5$)	Acid-base, redox, potentiometric titration	Scientific method and critical testing, observation and measurement, interpretation and analysis
Simple redox reactions ($N = 4$)	Burning a candle, burning iron wool, burning matches in a test tube with a balloon	Science and questions, hypothesis and prediction, interpretation and analysis

important information and making the right conclusion (SI) involves discussing the role of evidence and interpretation in general (NOSI).

The ‘Skills’ category contains codes that aim at students’ manipulative skills. All 14 teachers addressed the ‘Skills’ category (Table 3). These are closely related to SI and potentially to NOSI. The most prominent learning objective in this category was that students should know how the technique of a certain chemical procedure works. This seems to imply that students are asked not to change anything about the labwork but memorize it like a recipe. This makes it a goal of low cognitive demand. Five teachers clearly stated that the students should learn to actually perform a certain chemical procedure. Here, the focus is clearly on manual skills. Still, a recipe approach to labwork is used. Only three teachers stated that the students should be able to adapt the procedure, for example:

> We tried to react copper oxide and charcoal. […] It did not work for most of the class, when they simply mixed the substances. So, I wanted them to try different ratios to gain copper from copperoxide. (L5)

In this case, they go beyond reproducing a recipe. The focus is still on the practical manipulation but it also hints to the cognitive and even creative challenge of optimizing a procedure.

The ‘Teaching’ category contains the teachers’ goals that are not learning objectives. Twelve teachers identify at least one aim that falls into this category (Table 3). Eight teachers state the belief that doing an experiment will help their students to better remember the scientific content knowledge (‘inquiry as teaching method’) that is addressed in a lesson, for example:

> The effects will support the theoretical knowledge. It stays on their minds. (PT7)

One might argue that such a statement is a conceptual learning objective from labwork. We, however, argue that the teachers only aim to reinforce a concept that has already been addressed through previous instruction.

In summary, teaching how to do SI is a goal that most teachers in our study have when using labwork in the Chemistry classroom. However, all teachers also want their students to be able to simply perform the manipulations involved. Furthermore, most teachers also have at least one additional goal that guides their use of labwork in their teaching. This shows that labwork plays a variety of roles in the teachers' chemistry classrooms.

Teaching NOSI Aspects Using Labwork

In the discussion of their practices, teachers find examples from their own teaching where they include NOSI aspects in labwork (Tables 4–6). However, there are two NOSI aspects that the teachers do not seem to connect strongly with chemical labwork: 'science and questioning' and 'diversity of scientific methods'. Six teachers provide examples of how to teach about the diversity of scientific methods using labwork, for example:

> Science uses a variety of methods or approaches. For example, when you perform the titration of a beverage that is colourless like Sprite. You can simply do that with an indicator. But you can also use a pH-meter. You can talk about the advantages and disadvantages of different procedures. (T1)

This example and similar statements (Table 4) indicate that the teachers appreciate diversity of scientific methods as diversity in laboratory techniques rather than diversity of general investigation design (experimental, correlational, descriptive). This would be in line with their strong emphasis on the goal of conveying the scientific method described above (Table 3).

Only 5 of 14 teachers provide examples for 'science and questions'. The main difficulty seems to be to fulfill the demand of a cyclical process. The one cyclical process that teachers illustrate with labwork are experiments around the law of the conservation of mass:

> Iron wool gets heavier, the candle becomes lighter. […] What does really have an influence on the mass? How is it possible that you see that the mass still changes when the substances cool down? These things are an opportunity to talk about that [science and questions]. (T4)

The teachers point out that contrasting the burning of a coal ('loses' mass) and the burning of iron wool ('gains' mass) on a scale in an open system can be used to show how different observations of the same phenomenon (burning) generate new questions and in consequence hypotheses and predictions. They seem to regard this as a prototypical opportunity to talk about the role of questions in science. It remains unclear, however, how deep the teachers go into the NOSI aspect of science and questions.

So far, the two seemingly problematic NOSI aspects were described. If the problem is approached from the perspective of what chemical labwork is used to teach about NOSI, one can see that only three groups of procedures seem to be popular across teachers (Table 6). Seven teachers state that test reactions can be used to teach about NOSI aspects. The teachers see these tests most strongly associated with ‘scientific method and critical testing’. They stress that test reactions can be used to address the function of controls and blinds. This is not surprising as the principle of test reactions—identifying a certain substance in an analyte through chemical reaction with a test substance—lends itself to inquiry set-ups that use controls (analytes that do not contain the substance and will not trigger the test reaction) and blinds (analytes that contain the substance and will definitely trigger the test reaction). Five teachers state that titration can be used particularly well to illustrate ‘observation and measurement’ and ‘interpretation and analysis of data’. The teachers point out that in conducting titrations the students are forced to (a) handle larger data sets, (b) repeat an experiment to get an exact result and (c) acknowledge that their interpretations rely on their prior knowledge:

> I would use titration simply because you get data sets that contain more than just four data. (T5)
> in a titration, you have to do three, four, five, six titrations (PT7)
> They know the titration and they know that usually you do a neutralization reaction. […] And now they realize that what they thought was the equivalence point does not have to be neutral. […] Then we start looking at titration curves and develop a theory of what equivalent means and what could be appropriate indicators. (T4)

Finally, four teachers explain how three burning procedures (Table 6) can be used to talk about NOSI, particularly about ‘hypothesis and prediction’ but also about ‘science and questions’ for the reasons described above. Having described these three groups of procedures as relatively popular among the teachers, the teachers’ incorporation of NOSI in these inquiries is very tentative. Otherwise, there is a lot of diversity as to what opportunities the teachers use to talk about NOSI during labwork. This indicates that apart from a few more widespread examples, the incorporation of NOSI really remains with the individual teacher’s ingenuity.

In summary, the teachers in our study seem to find a number of examples of how to connect most of the NOSI aspects with labwork in their Chemistry classroom. ‘Science and questioning’ and ‘diversity of scientific methods’ stand out because examples are only provided by relatively few teachers and the examples also do not always cut to the core of the NOSI aspects. Teachers seem to agree only on a limited number of procedures for teaching NOSI, apart from which they take very individualized approaches. The teachers associate them mainly with the NOSI aspects that they seem to prefer generally. Burning reactions, however, are also associated with the otherwise difficult aspect ‘science and questions’.

Potential Criteria to Identify Labwork Particularly Suitable to Teach NOSI Objectives

The teachers describe a number of criteria for labwork during the interviews. Many of these apply to the use of labwork in the classroom in general but two of them have direct implication for the teaching of NOSI during inquiry (Table 5). Nine teachers state that a chemical procedure should have adjustable parameters to be useful for teaching about NOSI. The reasoning behind this seems to be that this will allow students to see that you can come to different observations, have to repeat a procedure to achieve reliability and/or have to adapt procedures to make a useful observation. In turn, this will allow addressing the NOSI aspects related to these. Nine teachers demand that the students should be able to understand the procedures with limited chemical content knowledge if they are to learn about NOSI. This indicates that teachers regard NOSI itself as a difficult topic. If teachers want to teach about it, they want the Chemistry which is used in the lab to be simple in order to be able to make the students think about NOSI.

In summary, the teachers state that the ideal labwork for teaching about NOSI requires a relatively low level of content knowledge to reduce the cognitive load for the students but, at the same time, the procedure has adjustable parameters so that the students can actually experience something about the NOSI aspects the teachers want to talk about.

Comparison of Ph.D. and non-Ph.D. Teachers Approach of Teaching NOSI

Finally, some of the results are unevenly distributed amongst Ph.D. and non-Ph.D. teachers. Both groups of teachers seem to approach the role of questions in science in different ways. Both groups also seem to attribute a different role to NOSI in their professional career.

Only Ph.D. teachers (six out of eight) explicitly state as a goal that they their students should learn about the role of questions in choosing the labwork for their investigation (Table 3). This indicates that they strongly believe in the importance of questions as guiding the following investigation. However, only one of these teachers (PT6) can provide a concrete example of his practice of teaching about science and questions in the lab. On the other hand, half of the non-Ph.D. teachers (three out of six) provide examples from their teaching practice regarding science and questions. This discrepancy might suggest that the role of questions in science is more deeply appreciated by Ph.D. teachers but that on the level of incorporating the issue in the classroom, non-Ph.D. teachers are more imaginative in creating NOSI learning opportunities, potentially due to their higher levels of pedagogical and pedagogical content knowledge.

On a more general level, only the Ph.D. teachers state explicit links between the NOSI framework and their identity. In these statements, they refer to their former activities at university, for example:

> I have internalized all of that. Perhaps through my PhD studies. To me, it's self-evident to start with a question, develop hypotheses, decide on an investigation, test and re-test, interpret diagrams. (PT8)
>
> You don't make an experiment just for fun. You do it because there is a question behind it. That is common knowledge in science. (PT3)

However, they often follow these statements up explaining that this is difficult to convey in school. They feel restricted by the structural issues in school like timing of lessons and the curriculum, for example:

> But it's sometimes difficult to bring that into the classroom and carry it through different lessons, when they are always interrupted by the bell. (PT8)
> It's impossible if you have prescribed content. (PT6)

A tentative interpretation of these statements might suggest that Ph.D. teachers have the knowledge and the intention to teach NOSI but do not feel well-prepared to do so under the constraints of the school classroom.

Discussion and Conclusions

Looking at the results, four central findings can be reported: (1) The teachers' current goal structure for using labwork in the Chemistry classroom only partly allows for teaching about NOSI. (2) Some NOSI aspects seem to be currently more easily reconcilable with teaching through labwork in Chemistry than others. (3) Two criteria seem to be helpful to decide whether labwork is likely to be useful in teaching NOSI: adaptable parameters and low level of required content knowledge. (4) The Ph.D. teachers' appreciation of the role of NOSI in general and particularly of the role of questions in science appears to be different from non-Ph.D. teachers' views.

It seems that teachers see the teaching SI as one of their major goals while using labwork. However, the only aspect that touches NOSI is the teachers' goal of conveying 'a scientific method'. This is in line with our analysis of the German national standards (KMK, 2005). Otherwise, the emphasis is on the doing of inquiry. This finding also corresponds with earlier findings, where developing skills was one of the teachers' highest ranked goal categories (Welzel et al., 1998). Teaching about NOSI does not seem to be a prominent goal for teachers.

When explicitly asked about their teaching of NOSI in the classroom, the teachers found most NOSI aspects reconcilable with their classroom laboratory practice. This is surprising given the skill-orientated phrasing especially of the 11–16 standards. This points to the inextricable link between NOSI and doing inquiry. It does not, however, advocate an implicit teaching of NOSI. Furthermore, two aspects 'science and questioning' and 'diversity of scientific methods' appear very rarely in the Chemistry classroom. The absence of 'diversity of scientific methods' could be a result of normative demands on the teachers from curriculum and teacher training (Ministerium für Schule und Weiterbildung des Landes Nordrhein-Westfalen, 1999; Schmidkunz & Lindemann, 1992). Unfortunately for science education, the difficulty of teaching about questions in the science classroom is in accordance with earlier findings (Chin & Osborne, 2008; Hofstein & Kind, 2012). Looking more closely at classroom practice, the teachers seem to share only a limited number of ideas about what labwork to choose for teaching NOSI. This indicates that teacher training, professional development and educative materials have not yet had a great impact in streamlining tested approaches of teaching NOSI to the teachers.

Finally, results from this study indicate that German Chemistry teachers holding a Ph.D. have a different appreciation of NOSI than their colleagues without a Ph.D. in Chemistry. Such a difference has not been reported so far. On the one hand, Ph.D. teachers in our study regularly made links between NOSI and their research experience. They also stated dealing with questions as an important goal of labwork. On the other hand, they seem to struggle even more to incorporate this particular aspect into their teaching. One might suggest that their more in-depth experience of research has made them more aware of NOSI, while at the same time their more on-the-job training for teaching has not prepared them with sufficient pedagogical and pedagogical content knowledge to bring these experiences and convictions to their classrooms.

Overall, this study indicates that teaching NOSI through inquiry is not habitual for Chemistry teachers. This confirms earlier findings from other countries (Hofstein & Kind, 2012). However, this study should still encourage educators and researchers to develop a culture of teaching NOSI through inquiry. Different measures could be taken. Science teacher education in Germany should be scrutinized. Do Ph.D. teachers really have a more profound appreciation of NOSI? Does a lack of pedagogical content knowledge explain why Ph.D. teachers do not easily find ways of teaching about NOSI? Normal Chemistry teacher students also have to take laboratory courses. Can this research experience be more fruitfully incorporated to build knowledge about NOSI? Professional development is key. Currently, professional development in Germany does not address the issue of how to teach about inquiry. In the future, professional development on NOSI should explain to teachers the relations and differences between SI and NOSI. It should also empower teachers to use adaptable and simple laboratory activities—as suggested by the teachers in this study—for teaching NOSI. Evaluation of such professional development should identify whether this can help teachers to regularly show the links between doing inquiry and NOSI in their classrooms. Furthermore, textbooks should be examined. These are widely used by teachers to prepare and deliver instruction (Banilower et al., 2013; Beerenwinkel & Gräsel, 2005). How are SI and NOSI represented in recent curriculum materials and textbooks? Their content influences teaching culture and, thus, has an influence on how NOSI is introduced to the classroom.

Finally, the findings of this study are subject to a number of limitations. First, it was not independently tested what views about NOS and NOSI the teachers held although these views might have influenced their teaching styles (Wallace & Kang, 2004). On the one hand, it would have been difficult to recruit participants for the interview if they had had to undergo a test procedure beforehand. On the other hand, this study did not aim to describe the styles of individual teachers but to create an aggregate description of the chances and obstacles for teaching about NOSI in German chemistry classrooms. Secondly, teachers were allowed to but not explicitly encouraged to access their curricular materials during the interviews. Thus, we might have received an incomplete picture. Finally, data were not triangulated through direct observations of the teachers' actual classroom behavior and its impact on student learning about NOSI or analysis of teachers' classroom materials. Yet, this discussion illustrates how this study can be used to inform further research on the issue of NOSI teaching and also provide impetus for science teacher education and professional development.

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Notes

1. In Germany, the three sciences biology, chemistry and physics are traditionally taught separately. The national standards also treat them separately. As this article focuses on chemistry, only the Chemistry standards are described. They are organized in four areas of competencies: content knowledge; SI; evaluation; communication.
2. North Rhine-Westphalia is the most populated federal state in Germany. Its 17.5 million inhabitants make up about one-sixth of the total population of Germany (Statistische Ämter des Bundes und der Länder, 2014).

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