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Teachers' language on scientific inquiry: methods of teaching or methods of inquiry?

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Abstract

With a focus on the use of language related to scientific inquiry, this paper explores how 12 secondary school science teachers describe instances of students' practical work in their science classes. The purpose of the study was to shed light on the culture and traditions of secondary school science teaching related to inquiry as expressed in the use of language. Data consisted of semi-structured interviews about actual inquiry units used by the teachers. These were used to situate the discussion of their teaching in a real context. The theoretical background is socio-cultural and pragmatist views on the role of language in science learning. The analysis focuses on two concepts of scientific inquiry: hypothesis and experiment. It is shown that the teachers tend to use these terms with a pedagogical function thus conflating *methods of teaching* with *methods of inquiry* as part of an emphasis on teaching the children the correct explanation. The teachers did not prioritise an understanding of scientific inquiry as a knowledge goal. It is discusses how learners possibilities to learn about the characteristics of scientific inquiry and the nature of science are affected by an unreflective use of everyday discourse.

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Introduction

The call for scientific literacy as a general goal for science education has emphasised the need for students to develop an understanding beyond scientific concepts and skills. An understanding of scientific inquiry and the nature of science (NOS) is regarded as fundamental to scientific literacy (Roberts, 2007). Today, many policy documents, curricula materials and programmes world wide are based on the idea that inquiry should be a guiding principle in science education (National Research Council (U.S.), 1996; Rocard, 2007). Despite the diversity and situatedness of research on inquiry based science education (IBSE) internationally, Abd-El-Khalick et al (2004) found that many themes and issues cut across national boundaries – supporting the relevance of the present study.

The idea that inquiry should be a guiding principle in science education is not new. Neither is the idea that students need to develop an understanding of what scientific inquiry is and some insight into NOS (DeBoer, 1991). At the beginning of the last century Dewey wrote extensively about the idea of inquiry as an organising principle in education and particularly in science education (Dewey, 1910, , 1916/2004). However, the promotion of inquiry in science education has been accompanied by widespread confusion about its meaning. Almost twenty years ago DeBoer (1991) concluded that teachers continue to be unclear about the meaning of inquiry and confuse the idea of inquiry as a teaching strategy with inquiry as a learning outcome. In Sweden, arguments about practical work in science education in terms of a content to be learned or as pedagogical strategy were mixed considerably already at the time of Dewey (Kaiserfeld, 1999).

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Research question and purpose

The objective of this paper is to qualitatively describe the different ways in which secondary school teachers' talk about and conceptualize scientific inquiry. The purpose is to contribute to an understanding of teachers' reasoning in relation to inquiry in science education.

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Although this is mainly relevant for teacher educators and developers of curricula materials, it also points to distinctions of language use that can be both inspiring and useful for teachers directly. The framing research question for this paper is: How do secondary school science teachers use terms related to scientific inquiry? In the analysis we focus on the terms hypothesis, experiment and laboratory work and discuss the possible implications of how these terms are used in learning about scientific inquiry and NOS.

Inquiry and nature of science

According to Lederman (2004), scientific inquiry refers 'to the systematic approaches used by scientists in an effort to answer their question of interest'(p. 309). In other words, there is no single scientific method or algorithm. To exemplify this Lederman distinguishes between descriptive, correlational and experimental research. He defines experimental research as involving 'planned intervention and manipulation of variables ... in an attempt to derive causal relationships' (p. 309). However, he warns that experimental research is not representative for all scientific investigations and that identifying 'the scientific method' with the use of controlled experiments has resulted in the promotion of a narrow and distorted view of scientific inquiry.

Nature of Science (NOS) generally refers to the epistemology of science and science as a way of knowing. Even though there is a lack of consensus among philosophers of science about what NOS is and entails, this need not be an issue for K-12 instruction. Lederman (2004) has described a set of NOS characteristics for which there is a reasonable level of consensus and that are both relevant and teachable to K-12 students. Examples of these characteristics are that students should learn the distinction between an observation and an inference, that science involves the invention of explanations and that these inventions are theory-laden, and that scientific knowledge relies on empirical evidence.

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In order to facilitate discussions about NOS and scientific inquiry for educational purposes, Lederman (2004) suggests the following distinction: 'it is useful to conceptualize scientific inquiry as the process by which scientific knowledge is developed and, by virtue of the conventions and assumptions of this process, the knowledge produced necessarily has certain unavoidable characteristics (i.e. NOS)' (p. 308). This shows the close connection between scientific inquiry and NOS; however, there is still a serious ambiguity as to how scientific inquiry is presented in educational reforms and curricular documents. Generally speaking, scientific inquiry can refer to three different ideas in education: 1) a set of skills to be learned by students; 2) a cognitive understanding of the processes of inquiry, e.g. the logic of a controlled experiment; and 3) a pedagogical strategy (Bybee, 2000). Lederman (2004) argues that the third idea of scientific inquiry is most strongly communicated to teachers in reform documents.

Previous research

The increased interest in socio-cultural perspectives on teaching and learning has been accompanied by a focus on the role of language in science teaching and learning. For example in his seminal work *Talking Science* Lemke (1990) suggests that 'learning science is learning to talk science'. Yore, Bisanz and Hand (2003), in their review of research on language in science education, make clear that any kind of inquiry or hands-on activity must be complemented by an active engagement with language at all levels: speaking, listening, writing and reading. Just 'doing', 'exploring' and 'experimenting' are insufficient. Scientific inquiry, both in an educational and research sense, is conducted through highly developed uses of language (Wellington and Osborne (2001). Carlsen (2007) has suggested that an important area for further research is language as an educational outcome rather than just as a means. Furthermore, language-oriented activities must be accompanied by explicit instructions in terms of purpose, audience, style and role in science and knowledge building.

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(Crawford, Chen, & Kelly, 1997; Yore et al., 2003). Yore *et al* (2003*)* note that the quality and quantity of oral interaction in science classrooms is generally low and unfocused.

Learners do not necessarily develop an understanding of inquiry as a result of participating in inquiry activities (Trumbull, Bonney, & Grudens-Schuck, 2005). Similarly, learners do not generally develop an understanding of NOS as a result of engaging in scientific inquiry alone, regardless of whether the learners are school students, teachers or scientists (Schwartz, Lederman, & Crawford, 2004). For learners to develop an understanding of inquiry and NOS they also need, besides from the proper experiences, guided attention to and explicit reflection on these topics (Abd-El-Khalick & Lederman, 2000). A prerequisite for this is that teachers have an understanding of inquiry and NOS and such an understanding is intrinsically connected to teachers having a functional language in order to be able to help learners to reflect on these topics. Bartholomew, Osborne and Ratcliffe (2004) studied what factors that become important when teaching 'ideas-about-science' and concluded that they came to see teachers' use of discourse as particularly significant. In contrast to discursive patterns that only focus on factual knowledge, patterns that invite learners to formulate arguments and relate these to theory and evidence are important in modelling authentic epistemic reasoning. This result was corroborated by Kelly (2007) in his review on research on discourse practices in science classrooms. Because teachers direct how learners meet new discourses through interaction with different forms of language from different sources and in different contexts, studying their use of language is highly relevant (Leach & Scott, 2003).

Researchers have focused on teacher education and teachers' professional development to improve meta-knowledge of inquiry and NOS. Pre-service science teachers often have most of their experience with science from college courses. Unfortunately college courses in the natural sciences rarely go into any depth in teaching about scientific inquiry and NOS. Pre-service teachers need first-hand experience of inquiry as well as practice in translating these

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experiences into inquiry-oriented lessons in their own future teaching (Britner & Finson, 2005). Windschitl (2004) has described how pre-service teachers with an undergraduate degree in science often are well steeped in a school tradition which equates scientific inquiry with "the scientific method". However, the scientific method, as an algorithm of a few steps performed in a linear fashion has been recognized as seriously misrepresenting science (Rudolph, 2002). Also, Windschitl and Thompson (2006) found that pre-service teachers, even with experience of authentic scientific inquiry, are not used to reflect on the role of theories, models and hypotheses in scientific inquiry. To create successful courses it is important to know about teacher students' and teachers' conceptualizations of inquiry (Windschitl, Thompson, & Braaten, 2008b).

Teachers' conceptualizations of inquiry are more complex that those of teacher students because they often take into account wider dimensions of the school context. Nevertheless, teachers are often better at articulating what inquiry is not, rather than what it is, e.g. it is not following a step-by-step procedure, just reading the textbook or getting answers directly from the teacher (Lotter, Harwood, & Bonner, 2006). Moreover, teachers' use of inquiry-based practices were found to be guided by four core conceptions, viz. those of science, their students, effective teaching practices and the purpose of education (Lotter, Harwood, & Bonner, 2007). Kang and Wallace (2005) found that teachers' naïve epistemological beliefs, but not necessarily their more sophisticated beliefs, were reflected in their use of laboratory activities. They suggested that this was because teachers had to negotiate their epistemological beliefs as part of the teaching context and their educational goals. Evidently, there are tight interconnections between teachers' inquiry teaching practices and educational goals.

Luft (2001) studied how teachers' beliefs and practices of inquiry changed as a result of participating in a professional development programme and found that inexperienced teachers

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changed their beliefs more than their practices whereas more experienced teachers changed their practices more that their beliefs. In a similar study teacher students were found to acquire a deeper understanding of inquiry as a result of a pre-service course on inquiry if they already had a more developed conceptualization of inquiry, whereas those who did not benefited less from the course (Windschitl, 2003).

Keys and Bryan (2001) draw attention to the lack of research on inquiry practices designed by teachers as opposed to by educational researchers. They recognize the need to develop a mutual language of overlapping cultures to frame, not only student-teacher interaction, but equally importantly researcher-teacher interactions. 'Only when the voices of researchers are in resonance with the voices of teachers can we begin to create harmonized reform-based instruction that is enduring' (p. 642). A similar conclusion was reached by Fredrichsen, Munford and Orgill (2006). They concluded that it is critical to support ways for teachers and teacher educators to participate in each other's communities of practice. Most studies on inquiry-based teaching have involved programmes designed by researchers and taught by expert teachers; therefore more studies of how teachers ordinarily use and conceptualize inquiry on their own initiative are needed. Also, since most studies involve elementary and middle-school teachers and students, more studies on inquiry practices in secondary schools are needed (Keys & Bryan, 2001).

Method

Theoretical perspective

With this paper we want to contribute to more efficient communication between three cultures: those of teacher educators, teachers and students. To do this we emphasise that learning is not always unidirectional, i.e. students learning from teachers. Teachers may take the role as students in communications with teacher educators during in-service training and

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teacher educators may learn from teachers and students about their current realities in the classrooms. In this study however, we focus on teachers and note that it is their culture and traditions that binds these three domains together. Teachers are also students and have many years of socialization in school science behind them.

In this paper we take a pragmatist and socio-cultural perspective on language and learning. From a pragmatist perspective on language, the meaning of a word is its use and function in a specific activity (Wickman & Östman, 2002b). A socio-cultural perspective on learning means seeing learning as appropriation of discourse in a situated socio-historical context (Wertsch, 1998). Although science is characterised by a rich synthesis of linguistic, mathematical and visual representations (Lemke, 2001), conceptual learning is orchestrated through a discourse that require spoken and written language. Learning to see what is relevant in an investigation is reciprocally connected to and often inseparable from learning to talk about it or learning the relevant language game (Bergqvist & Säljö, 1994; Wickman & Östman, 2002a). A consequence of this is that what teachers are able to notice, and therefore teach in science, depends on how they use language to make certain distinctions. A prerequisite for teachers and students to gain access to words and concepts to talk about scientific inquiry, and thereby participate in it and develop an understanding of the characteristics of scientific inquiry, is that their teachers introduce and use a relevant language that makes this possible.

This study is based on interview-conversations between a teacher and a researcher/teacher educator about the teachers' use of inquiry oriented approaches. These conversations revolved around the teachers describing their own teaching approaches and it is within this activity that the words analysed in this paper have meaning. By centring the interviews on concrete examples brought by the teachers from their own teaching units (books, hand outs etc.), the conversations were situated close to their actual practice. As

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conversations between a teacher and teacher educator the interviews also were situated within the broader context of teacher education, i.e. the talk analysed in these interviews is the type of discourse teacher educators and authors of curricular materials will have to relate to.

The teachers: selection of participants

As the study was both explorative and qualitative, diversity was considered as being more important than a random selection of participants (Neuman, 2005). In order to achieve diversity in terms of different kinds of experiences and backgrounds, we based the selection on three criteria: years of experience as a teacher, equal number of men and women and schools in a variety of neighbourhoods. Twelve teachers were interviewed with teaching experience ranging between 5 and 30 years. The teachers' experience also varied with regard to in-service training with regards to inquiry practices.

Interviews

In order to obtain data on teachers' ways of describing their teaching, with a focus on inquiry oriented approaches, semi-structured interviews seemed to be the most natural starting point. Another possibility would have been to ask a series of questions about how they use inquiry in their teaching and how they work with particular aspects of language in such situations. Such a battery of questions would suggest certain types of answers and exclude others, however, and was considered too guided – especially considering that our initial aim was to form an overall picture of different possible ways of talking about inquiry. Cobern and Loving (2000) used a similar approach to the one adopted here in a study on teachers' enacted worldviews.

In describing teachers' use of language in relation to scientific inquiry in their own teaching, we thought it important to connect the interviews to an authentic example that the teachers had used in class. We therefore asked the teachers to bring an example (e.g.

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instruction for lab work) from their own teaching that they thought represented an instance of scientific inquiry (*ett undersökande arbetssätt* in Swedish). We defined instances of scientific inquiry quite loosely on purpose as 'instances in which the students themselves find out answers about nature through some kind of methodical study, experiment, field observations or similar'. Here the idea was not to place too strict a limit on what might count as inquiry. Also, by asking the teachers to bring an authentic example from their own teaching we wanted to situate the interviews in the teachers' actual classrooms to avoid the inclusion of too much romancing in their accounts (Kvale, 1996).

During the interviews the first author asked the teachers to describe their examples and used a template with terms and categories that were considered important and relevant to inquiry in school science (see next section: Terms to Talk about Scientific Inquiry). The intention was to ask the teachers about these terms in connection with the examples they supplied (Kvale, 1996). Even though a specific set of questions was not used, the following questions served as a tacit guide during the interviews.

1. What terms are important in the description of inquiry as a part of the teachers' practice?
2. What meaning do the teachers give these terms?
3. What function do these terms have as a part of their teaching?

This heuristic method was intended to produce an understanding of the teachers' use of language without losing track of the context of school science and their own way of describing their teaching. After establishing the examples and the words used by the teachers during the interviews, more explicit and probing questions were asked with regard to the meaning and use of certain words. Care was taken, however, to stay within the limit of the relevant context and example.

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Terms to talk about inquiry

Our purpose was to talk to the teachers about aspects of inquiry in science education in a rather general way and thereby get a sense of the language of inquiry used by secondary school teachers. In preparing for the interviews we did not make any particular distinction between differences of inquiry in terms of research methods, teaching methods or targeted knowledge in science education. Rather, our starting point was scientific inquiry as described in science education research and policy documents. Even though all authentic research in the natural sciences does not slot into the following structure, most academic research can be described in the following way in retrospect (Chalmers, 1999; Derry, 1999; Johansson, 2003):

1. There is a starting point to inquiry. This can usually be conceived of as a question to be addressed or a problem to be solved.
2. There are certain preconditions or a background against which the question or problem is posed. This can be previous research, theories or models which are either used or tested.
3. There are some characteristic ways in which inquiry proceeds to find answers to the question or solutions to the problem. These involve the use of certain methods, a striving for objectivity, and certain patterns of constructing arguments based on assumptions about cause and effect, empirical evidence, predictions and Occam's razor, etc.
4. The inquiry amounts to some sort of result or suggested consequences. Of paramount importance in the academic research tradition is the idea of public examination of research in the form of peer review. This means that to be deemed worthy, scientific inquiry must result in some form of logical presentation that is intelligible to others, usually in the form of a research report. In relating back to point 2, one could say that the starting point and end result of scientific research is the research report.

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Based on these reflections on scientific inquiry we formulated five categories of terms that we hoped to focus on or incorporate into the conversation in a natural way during the interviews in relation to the examples provided by the teachers. The first four are inspired by Lederman (2004) and the fifth was added as a link to the scientific practice of peer review.

1. Question: guess or hypothesis
2. Method: observation, experiment, scientific, systematic, objective
3. Previous knowledge: theory, model
4. Logical reasoning: critical thinking, evidence, cause, prediction
5. Presentation: report, review, comparison with other results

Data analysis

Data analysis commenced with transcription of the recorded interviews. After reading through these transcriptions a number of times and coding terms and sections related to inquiry, three particular terms were chosen for further analysis, namely, hypothesis, experiment and laboratory work (*laboration*, in Swedish) – the relevant sections of the transcriptions being categorised according to these particular terms. We then studied the meanings given to them by the teachers as they described their examples of inquiry units. In many cases the first author drew attention to the inquiry related terms during the interview conversations and asked the teachers to elaborate on them using the tacit questions mentioned earlier. Although the starting point for the conversations was the teaching units used by the teachers, the particular details of these are not necessary in order to understand the transcripts analysed in this paper, as will become evident later.

Results

Talking about inquiry using the terms described above in the conversations proved to be more difficult than we had anticipated. The teachers were more focused on the pedagogical aspects

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of inquiry and on learning goals in terms of exemplifying natural phenomena and motivating explanatory models. That is to say, the focus was on students' learning and understanding the products of science as opposed to the processes of scientific inquiry.

The examples provided by the teachers were mainly examples of practical tasks that the students worked with for one lesson or less. Educational goals expressed by the teachers included exemplifying a scientific concept (e.g. density) or theory (e.g. heat expansion), providing experiences of certain phenomena (e.g. earthworms), making theoretical tasks more concrete and linking them to real life experiences (e.g. calculating one's pressure on the floor), varying the teaching, fostering curiosity and having fun in science class. Our impression was that the main emphasis in terms of knowledge goal for the students was what Roberts (1982) called 'the correct explanation', and explained as 'the body of ideas accepted by the scientific community at any given time'. Exemplifying scientific inquiry seemed to be somewhat unusual in that it was only mentioned by two of the teachers and elaborated on by one. In the latter case the teacher gave an example of learning to control variables by working with a 'secret box', the content of which the students discovered by performing a variety of different tests.

Surprisingly few of the terms used by the teachers related specifically to scientific inquiry as conceptualized by us as researchers. In fact, the teachers only spontaneously mentioned two of the terms on the list when talking about their examples: hypothesis and laboratory report. The first author tried to probe and connect the other terms on the list to the teachers' examples, sometimes asking about their use and function explicitly. One concept that we thought might be particularly important was the concept of a research question and that scientific inquiries start from some kind of a question (Eggen & Kauchak, 2006; National Research Council (U.S.), 2000). This was explicitly addressed in all but two of the interviews, often using the term 'research question'. A related question was whether this was something

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321 the teachers used when talking with their students about instances of inquiry or laboratory
322 work, or in structuring their teaching. None of the teachers said anything to suggest that this
323 was an important concept in their teaching, or that 'research question' was a term they used.
324 Interestingly, one teacher returned to the idea of a research question much later, after it had
325 been brought up in the interview. She then used it in the sense of the students formulating a
326 question about what they wanted to or expected to learn from a unit of self-directed study in
327 biology. Although this can be said to be related to inquiry in the general sense of the word, it
328 did not relate specifically to scientific inquiry or learning about it.

329 In this paper we focus on the analysis of three terms that illustrate a certain feature of
330 the role of language in inquiry in secondary school science instruction: hypothesis,
331 experiment and laboratory work. The function given to the term hypothesis by the teachers
332 was primarily pedagogical, i.e. inquiry as a pedagogical strategy (Bybee, 2000), which we
333 argue contrasts with its function in scientific inquiry proper. The terms experiment and
334 laboratory work were used synonymously, which also may have consequences for the
335 teaching of scientific inquiry. These three terms have a particular function when talking about
336 or during scientific inquiry and are referred to here as belonging to the category *methods of*
337 *inquiry*, but in the interview context they were used by the teachers to talk about educational
338 activities, or *methods of teaching*. This is explained in more detail in the following sections,
339 starting with the function of the term 'hypothesis'.

340 *Hypothesis*

341 The term 'hypothesis' was the only term that all the participants except one said they used
342 when talking to their students. In six of the interviews this term was introduced by the
343 teachers themselves when describing how they worked, and in five cases the interviewer
344 brought it up in relation to their examples. In the one case where it was not used, the example
345 contributed by the teacher was so far removed from anything resembling scientific inquiry

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that it was deemed irrelevant to ask about its usage. All the teachers seemed to use 'hypothesis' as meaning an educated guess about what might happen in a laboratory task or exercise. The term was given an important role and the students were often asked to state their hypothesis as a regular part of laboratory work. The function given to this term by the teachers seemed to be synonymous with that of a 'prediction', although this was not a term that any of the teachers volunteered. In six of the interviews, the teachers were explicitly asked whether 'prediction' was a word they used, and the answer in each case was 'no'. This is not very surprising given that their use of the word 'hypothesis' made 'prediction' superfluous, as one of the teachers also noted.

In contrast to the meaning the teachers gave to 'hypothesis' in this study, this term usually has a different meaning in science studies and science proper. Here a hypothesis refers to a possible or preliminary explanation of an observation or phenomenon. In science it is common to put a lot of effort into formulating hypotheses in such a way that they can be tested through some type of investigation and thus either be refuted or gain credibility. Part of the logic of hypothesis testing is that one can derive predictions based on them, which is normally what is then compared with the evidence at hand, so the actual hypothesis is often tested indirectly. In this way the formulating and testing of different hypotheses can be part of cycles of scientific inquiry aimed at describing nature by constructing ever more satisfying theories (Chalmers, 1999).

The following quotes show how the teachers described the meaning of the term 'hypothesis' as they wanted their students to use it – an educated guess as to what they thought might happen when performing a laboratory task.

Interviewer: So, if someone asked, what would you say then?

Alfred: What a hypothesis is? Well, then I would say 'what do you think will happen?', 'what is your guess?' A guess.

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Interviewer: Yes

Alfred: Or an assumption.

Peter: It ... in Year 7, you know, I always do these … shall we say, very trivial investigations. You boil water. So I have, they get to set up a hypothesis: 'Yes, how hot does the water get?' and 'How hot is it after boiling for five minutes?' and so on.

Interviewer: How do you explain it [hypothesis]?

Lina: What result do you think you will get? What do you think will happen?

The teachers' use the hypothesis as a call for students to take a stand or commit themselves to a guess as to what the laboratory task will result in. For instance, the result might be some kind of measurement, as in the case of the temperature of boiling water (Peter), or the nature or value of whatever is being studied. Alfred also adds "an assumption" to his description which could be read as an assumption about a possible explanation. This is however the closest statement any teacher made in this direction and based on the rest of the interview we believe it is better understood as an assumption about an outcome, i.e. a prediction. Several of the teachers pointed to the importance of students trying to connect to their initial hypotheses when writing a laboratory report. Thus, the meaning given to 'hypothesis' continues to structure the students' activities when the practical part of the laboratory work is over.

The hypothesis primarily has a pedagogical function in their practice as described by the teachers. By that we mean that the teachers ask the students to formulate a hypothesis, meaning an educated guess, before they perform a laboratory task, primarily to help the students learn the particular subject matter involved in the task. The pedagogical motivation

Deleted: Interviewer: . Do you talk about this as a hypothesis? ¶
Ingrid: . . Yes, what we write is: 'What do you think will happen?' Hypothesis – what do you think will happen? We use both, right. ¶
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Interviewer: . Do you talk about that, hypotheses? ¶
Ulrik: . . Yes.¶
Interviewer: . And what is that if you translate? ¶
Ulrik: . . Well, we have said it so many times now that we don't have to translate it anymore, hypothesis, they know how to set one up … You have an idea about how it's going to be, roughly so. ¶
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for this is that it helps the students to focus on what they are doing (Lina, below) and creates a situation that is meant to help the students to remember the science content that the laboratory task is meant to illustrate (Ann-Catherine). Furthermore, it draws the students' attention to their own preconceptions or how well they have understood or not understood the theoretical content being exemplified (Johan). Hence, it can also be seen as a way of creating conditions conducive to an aha-experience if the results are contrary to those expected.

Lina: And sometimes it can just be a way to sort of concentrate better, to think things through 'I see, yes but this should probably have been blue here' or, for them to sit down, yes be forced to think a little before one gets going. Otherwise they rush away to get everything and get going at once without them, then they don't know what they are doing.

Ann-Catherin: If you get the wrong [answer], it doesn't matter if it didn't turn out the way you expected, because then you have given it some thought. And then the brain works so that if you have thought about it, regardless of whether what you thought would happen did or didn't happen, it is easier to take in new things if you have thought about it first. But if you are completely empty it is harder to attach new things.

Johan: And what does hypothesis mean? That it is your educated guess, which as a rule is almost always wrong, but it doesn't matter because that's not what is graded. But, you know, that's where they have their previous knowledge from. So

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Deleted: Alfred: Many want to get started, you know, because they like the handicraft of laboratory work. But to pause for a moment before and think is harder you know. So they know what it means and signify but are sloppy about it. ¶
Interviewer: Do you have any tricks then or…?¶
Alfred: No, it's just, before they get started, then you so to speak go over the laboratory task and emphasise it, 'don't forget the hypothesis'. Sometimes I can say that you can't even touch the material until I have seen that you have a hypothesis.

Deleted: Lina: And sometimes it can just be a way to sort of concentrate better, to think things through 'I see, yes but this should probably have been blue here' or, for them to sit down, yes be forced to think a little before one gets going. Otherwise they rush away to get everything and get going at once without them, then they don't know what they are doing. ¶

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> that's where you can take your measure from and see later 'what did I learn from this?', 'This is what I thought … this I know, or I'm sure of then' … or, 'this is what I know now then'. It is not always one arrives at a conclusion.

What is made evident in these remarks is that the students are encouraged to formulate a hypothesis, as an educated guess, in order to become more aware of their own learning and have their own preconceptions be either challenged or confirmed. The pedagogical function is also partly to control the students' attention to the task at hand. One teacher (Christian) even said that he accepted a student's guess about the purpose of a laboratory task (to demonstrate the presence of reduced sugars based on the chemicals given to the students) as a hypothesis. His reasoning was that this demonstrated that the student had 'made the correct associations'.

Experiment vs. laboratory work

Another term that emerged as important in the conversations with the teachers was 'experiment' and its use as synonymous with laboratory work. The teachers seemed to use the term experiment in an everyday sense as synonymous with testing, trying or doing something without knowing what will happen. Therefore it is not strange that learning about experiments as a conceptual content was not present in the teachers' discourse. In fact, only two of the teachers in this study mentioned very briefly goals in terms of learning about scientific inquiry, thus suggesting that even though teachers occasionally might have such aims, they are not given a high priority. These two teachers also made no difference between the terms experiment and laboratory work.

We had not thought about distinguishing between the terms experiment and laboratory work prior to the interviews and this was an insight that evolved during the study. Reflecting on how the term experiment is more commonly used in science inspired us to make a distinction between an experiment as a *method of scientific inquiry* and laboratory work as a

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method of teaching science. Although experiment has an everyday meaning that is synonymous with testing or trying, in science the term 'experiment' is often used as an abbreviation for 'controlled experiment', which is a technical term with a more precise meaning. Different types of controls are used in different experimental set ups, as illustrated by further specifications in the relevant terminology e.g. double-blind experiments and quasi experiments. However, one could say that in essence the logic of a controlled experiment in scientific inquiry is to make some change in a system and observe the result while trying to control all the other variables thought to influence the result. The method is primarily useful when studying causation and functions. In this context a hypothesis is a possible explanation of the mechanism involved in the causation and is tested, often indirectly by deriving predictions from it, through a controlled experiment (Bock & Scheibe, 2001).

Laboratory work on the other hand as a *method of teaching science*, is a teaching strategy or pedagogical activity, and as such it can have many distinct goals (Hofstein & Lunetta, 2003). One goal could be to learn about controlled experiments as a specific type of method used in scientific inquiry to answer a certain type of question, usually about causal mechanisms. However, laboratory work could just as well be used for other educational purposes e.g. to illustrate phenomena or theoretical concepts and thus focus on a particular science subject matter as a learning goal.

The quote below shows how one teacher do not distinguish between the concepts of experiment and laboratory work and an investigation.

Interviewer: Do you talk about lab work then, or is it an experiment or an investigation or what?

Alfred: Well, ... I, I hardly know what the difference is between those three concepts [nervous laughter]. No, but I guess it is

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a laboratory task, an investigation, an experiment, I don't really know what the difference is but…

Interviewer: It is,

Alfred: Maybe there exists such a definition but …

Interviewer: Well, I am not sure about that, rather, what I am interested in is if it is used in any specific way. So if any difference is made between such words, if it matters or not?

Alfred: No, not, not for me I don't think it does.

Interviewer: Mm [OK]

Alfred: No, I guess I use all three concepts a bit sloppily.

Interviewer: Mm [OK]

Alfred: I should think. Yes, I have never thought about it but yes I do.

Alfred seemed surprised by these questions and so did Sonya, Martin and Ingrid which further illustrates how these teachers do not distinguish between the terms experiment and laboratory task and that this seems to be an unusual topic for them to reflect upon.

Interviewer: Do you talk about, eh, laboratory tasks and experiments with the students as different things? Or is it the same thing, or?

Sonya: Yes … that … I don't think I have talked with them about that at all actually.

Interviewer: What would you say a laboratory task is? And an experiment? Is there any difference in school?

Sonya: (pause) No … we have never thought about that. Except if … now we do an experiment or now we do a test, now we do some lab work.

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Interviewer: Mm

Interviewer: Would you say that there is any difference between a laboratory task and an experiment when you speak in your classroom?

Martin: Eh, no not in my opinion. I don't know what you mean now?

Interviewer: Well, what you call the things you do.

Martin: Yes …. No, but I don't know. No I say laboratory tasks, but they often say experiment.

Interviewer: OK

Martin: But I usually don't say that. Ehm. I believe they think its quite fun to do lab work, … actually.

Interviewer: Mm

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Interviewer: Do you talk about then, since you brought it up now, I asked if hypothesis was a word you needed to explain, and then, in the next step? Do you talk about experiment, method, observation? Do you make any…

Ingrid: Well no, not anything specific like that. Laboratory work is what we use you know. That concept we use. We do lab work, we do things so to speak, that's what it's about, and that's evident. 'Experiment' I don't use that much, perhaps I should do that?

Another aspect of the use of the term experiment was that it seemed to be unproblematic and used in an everyday sense. In particular learning to do an experiment or an

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investigation was unproblematic and not something the students needed to be taught or practice. Lina contributed an example that clearly could be used to illustrate a controlled experiment. Her students were expected to examine earthworms to find out what sort of environment they liked. They were supposed to find this out by doing two experiments in which the dependent variable was where the earthworms liked to be and the independent variable was either the amount of light or the degree of moisture preferred. However, during the interview she talked about this in quite a different way:

Lina: And then, there's one [assignment] where they are supposed do an experiment and investigate whether the earthworm prefers light or darkness: 'write down how you did it and your result in your journal', and then the idea is that they shall think through how, how to best do that then. How can you start to organise it? They sit together in groups of three so that they can discuss. Then I guess each one should write, but they can work together.

Interviewer: Do you talk about what an experiment is then?

Lina: We have done that quite a lot. When we have written lab reports and such.

Interviewer: Yes

Lina: When we, a lot when we were in the chemistry classroom and did some lab work and so.

Interviewer: Do you make any distinction between a laboratory task and an experiment?

Lina: No, I don't think so. Not for them. No.

[Later in the same interview]

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Interviewer: . Mm. And then you mentioned hypothesis. ¶
Catherine: . Yes.¶
Interviewer: . Apart from that this is something different than just 'atom' and 'beaker', those are more like specific, 'hypothesis' is something that can occur in any natural science subject.¶
Catherine: . Yes.¶
Interviewer: . Other subjects too, it doesn't have to be natural science ...¶
Catherine: . Mm.¶
Interviewer: . Or also experiment, observation, have you also discussed such things?¶
Catherine: . Ehm… No … Experiment, yes, maybe that I have explained that word yes …¶
Interviewer: . Now you are thinking about Year 6?¶
Catherine: . Yes, exactly, now I'm thinking about Year 6. ¶
Interviewer: . And what about Years 7, 8 and 9? ¶
Catherine: . Then you take it for granted that they should know what this word is, experiment, what it stands for. ¶
Interviewer: . . Mhm, Do you make any difference between laboratory work [laborationer] and experiments like that?¶
Catherine: . Ehm, no I can't say that I make any difference. ¶
In Catherine's statement, experiment seems to be something unproblematic in that she does not reason about it in terms of something to be conceptually understood or as a targeted knowledge. At the same time the students are expected to understand and be familiar with what an experiment is since they use it in order to learn other things. As became evident in the rest of the conversation, Catherine was not clear about the meaning of a controlled experiment. ¶

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Interviewer: Can you think of some concrete example?

Lina: Well…

Interviewer: Where you have practiced how you come up with your own experiment?

Lina: No, that you don't have to practice.

Interviewer: No?

Lina: Come up with, they think that …

Interviewer: OK

Lina: I mean, it is more like 'yes, can I do', sort of 'can I do it any way I want to?', 'Yes, just let me know how you want to' .. it … we've studied electricity and a little of that where they should connect light bulbs and they think it's great if they get to do whatever they like.

Interviewer: Mm, of course. I thought more about if you, eh, want to prepare a … ehm, something more systematic, to collect worms in a special way. Then you have to think through it a little more carefully how to do it beforehand, right?

Lina: Mm

Interviewer: Perhaps … This is a little like designing an experiment, or designing an investigation you could call it.

Lina: Mm, a very small [investigation]…

In this excerpt Lina talks about the assignment as an experiment, although in the rest of our conversation, and particularly when specifically asked about this, she made no distinction between experiment and laboratory work or investigation. Her comment that practising how to design and carry out an experiment was not necessary shows that she does not talk about

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this as a conceptual or procedural knowledge goal indicating that scientific inquiry is unproblematic. Allowing the students to 'experiment' mainly has a pedagogical function in that the purpose is that the students are supposed to be kept active and think that science is fun, and bring in an element of play.

As a further illustration, Catherine in the quote below, seems to talk about an experiment as unproblematic and does not reason about it in terms of something to be conceptually understood or as a targeted knowledge.

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Deleted: Sonya and Martin were also somewhat puzzled when asked whether they made any distinction between 'experiments' and 'laboratory work'. Sonya's expression is quite revealing and again suggests that, in terms of targeted knowledge, scientific inquiry is not something she has reflected about.

Interviewer: Mm. And then you mentioned hypothesis.

Catherine: Yes.

Interviewer: Apart from that this is something different than just 'atom' and 'beaker', those are more like specific, 'hypothesis' is something that can occur in any natural science subject.

Catherine: Yes.

Interviewer: Other subjects too, it doesn't have to be natural science ...

Catherine: Mm.

Interviewer: Or also experiment, observation, have you also discussed such things?

Catherine: Ehm… No … Experiment, yes, maybe that I have explained that word yes …

Interviewer: Now you are thinking about Year 6?

Catherine: Yes, exactly, now I'm thinking about Year 6.

Interviewer: And what about Years 7, 8 and 9?

Catherine: Then you take it for granted that they should know what this word is, experiment, what it stands for.

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Interviewer: Mhm, Do you make any difference between laboratory work [laborationer] and experiments like that?

Catherine: Ehm, no I can't say that I make any difference.

Catherin does not seem to think the concept of an experiment merits special attention, yet at the same time the students are expected to understand and be familiar with what an experiment is since they use it in order to learn other things. As became evident in the rest of the conversation, Catherine was not clear about the meaning of a controlled experiment.

These excerpts from the interviews with Alfred, Sonya, Martin, Lina and Catherine show that for them the terms laboratory work and experiment are synonymous and indicate that they do not reason about scientific inquiry in terms of a conceptual targeted knowledge. We do not claim that the teachers, when they use the terms experiment or laboratory work, "actually have in mind" either a pedagogical strategy or a particular research method such as a controlled experiment, although it is possible. The point is that there is nothing to suggest that they differentiate between the notions of an experiment and laboratory work in terms of *methods of teaching* or *methods of inquiry* when they talk about their teaching. This is a distinction we have introduced to make sense of how and why the teachers mix these terms and seem so perplexed when asked about them. From our theoretical perspective the meaning of a word is in its use in a particular situation. Thus, in the situation of a teacher talking with a teacher educator and researcher about inquiry the terms experiment and laboratory work have the same function and meaning. Furthermore, if these conversations also reflect how these teachers talk with their students, the students' possibilities to learn about the characteristics of certain *methods of inquiry* are thus lost in an unreflective use of everyday discourse.

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Interviewer: . What would you say a laboratory task is? And an experiment? Is there any difference in school?¶
Sonya: . . (pause) No … we have never thought about that. Except if … now we do an experiment or now we do a test, now we do some lab work. ¶
Interviewer: . Mm¶
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Interviewer: . Would you say that there is any difference between a laboratory task and an experiment when you speak in your classroom?¶
Martin: . Eh, no not in my opinion. I don't know what you mean now?¶
Interviewer: . Well, what you call the things you do. ¶
Martin: . . Yes …. No, but I don't know. No I say laboratory tasks, but they often say experiment.¶
Interviewer: . OK¶
Martin: . . But I usually don't say that. Ehm. I believe they think its quite fun to do lab work, … actually.¶
Interviewer: . Mm¶
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Discussion

Summary of results

In the analysis we have tried to show how use of the terms hypothesis, experiment and laboratory work mix two categories of methods, namely, *methods of teaching* and *methods of inquiry*. In terms of knowledge goals associated with scientific inquiry, this means a conflation of means and ends. In other words, while 'hypothesis' and 'experiment' are used in a way that aims at achieving learning goals associated with science content as a product, e.g. theories, facts and models, the possibilities of developing a language to both talk and learn *about* scientific inquiry and NOS seem to be limited.

We began with the assumption that in order to develop scientific literacy it is necessary to have a grasp of how theories, knowledge claims, definitions and explanatory models are developed in science. Learning about scientific inquiry can, for example, mean learning something about the rationale and logic of scientific research methods. It can mean to understand that scientific inquiries begin with a question and that a hypothesis is a preliminary answer to that question or explanation of the phenomenon of study, often of causal nature, and that a controlled experiment is a special method or type of investigation.

The result presented here suggests that in their teaching the interviewed teachers do not reason about understanding scientific inquiry as conceptual knowledge. Instead they appear to focus almost exclusively on knowledge goals in terms of learning the products of science and the use of this knowledge. In order to achieve this aim they use certain *methods of teaching,* which they describe as laboratory work, laboratory tasks and investigations or experiments without differentiation. The students are asked to formulate hypotheses (guess the answer) with the purpose that they learn and remember the correct explanation. One way of clarifying the use of these terms in relation to scientific inquiry as targeted knowledge in school is to differentiate between the categories of *methods of teaching* and *methods of inquiry*. In

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focusing on developing knowledge about the products of science, terms like experiment and hypothesis are subsumed under this purpose and functionally fall into the category of *methods of teaching*. If the learning of scientific concepts and theories was the only objective of the education this would not be a problem. But in order to learn about scientific inquiry these terms are needed conceptually as a part of the category of *methods of inquiry* to be able to learn the relevant distinctions of this aim. This would be an example of language as an educational outcome rather than just as a means (Carlsen, 2007). Further research is needed to establish exactly what teachers' language use is in the classroom and what it means for students' learning about inquiry and NOS.

Possible explanations

Language is dynamic and subject to constant change. Words and expressions often evolve in use and meanings change over time. In some cases the same word may have different meanings and connotations in different activities simultaneously, as the present study exemplifies. This is nothing new, and asking why a particular word is used in a certain way may not prove very fruitful, since this often depends on multiple factors and contingencies and whether the question demands a causal or teleological explanation. However, it is interesting to note that many science teachers are themselves the products of an 'archetypal education which has largely ignored the epistemic base and nature of its own discipline' (p. 659) (Bartholomew et al., 2004). Traditionally, higher education courses in natural science devote very little time and resources to reflection about inquiry and the nature of science. Why the teachers in this study use the terms hypothesis and experiment in an everyday type of language game may therefore reflect the way they have been taught natural sciences at university level. To study the correlation between teachers' educational background and experience with inquiry would have to be another study. However, we can note that the terms analyzed in this paper was used in a very similar way by teachers with highly diverse

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educational backgrounds. While earlier studies have shown an emphasis on the correct explanation in teacher education is important (Lager-Nyqvist, 2003), further studies are needed to ascertain what this might mean in terms of language use.

Possible implications

An interesting question relates to how using the terms analyzed here in particular ways restrains or affords reflection and understanding (Wertsch, 1998). In this study this amounts to asking how these terms relate to educational goals associated with inquiry. The conflation between terms relating to *methods of inquiry* versus *methods of teaching* can have problematic consequences. For example, the development of controlled experiments has been part of the development of science since the beginning of the scientific revolution and has been enormously significant (Chalmers, 1999). However, exactly what it is, what it is for or how it can be done it is not immediately obvious to someone new to science. One of the teachers said that he did not expect his students to arrive at Newton's theory of gravity simply by playing around with apples. Nevertheless, the way that he and most of the other teachers talked about scientific inquiry as a pedagogical activity, unproblematic in terms of conceptual learning, suggest that the students are expected to invent the principles of a controlled experiment themselves by being 'given freedom to explore stuff'. Even though one of the teachers (Ann-Catherin) gave an example of teaching the control of variables, she didn't talk about this as a controlled experiment, and seemed to have difficulty in finding words to articulate it.

A prerequisite for learning in institutional practices such as school science is that learners are given access to a relevant discourse. What learners are given an opportunity to distinguish depends on how language is used in reflecting on inquiry. This is so whether the learners are students, teachers or scientists. Terms such as 'hypothesis' and 'experiment' used to talk about and during examples of scientific inquiry are parts of such a discourse. Students

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learn about scientific inquiry by gaining access to such words, using them in action, and communicating and thinking with them in contexts in which they have consequences and become meaningful. If the term hypothesis is treated during inquiry oriented approaches in the way this study suggests, then an important dimension for learning about scientific inquiry is not available to explicitly reflect upon as part of the discourse the students are being introduced to. Some teachers clearly expressed that they considered it important that the students learn the correct language of science and use words in their correct scientific sense. This concern about teaching students the correct use of scientific terms contrasted sharply with the teachers' unreflective and everyday use of language in relation to scientific inquiry.

In addition to making communication about scientific inquiry more difficult, conflating the categories *methods of teaching* and *methods of inquiry* may also be an obstacle to an understanding of NOS. Let's have a look at what this might mean for some of the characteristics of NOS Lederman (2007) has defined as important for K-12 instruction. One aspect of NOS that may be more difficult to understand is the distinction between an observation and an inference. Based on how the teachers in this study used the term hypothesis, the students are left with observing and "guessing what will happen". However, making inferences from observations often entails reference to the causal propositions stated in a proper hypothesis.

A second example of NOS is that scientific knowledge is theory-laden. This is associated with understanding the creative dimension involved in formulating hypothesises as possible explanations. The formulation of hypotheses and the associated design of investigations to test their validity and reliability are based on theoretical assumptions and the results of previous inquiries, which is the essence of theory-ladeness. As Lederman (2007) puts it, 'science involves the invention of explanations'. An exclusive focus on predictions at the cost of understanding the role and function of hypotheses as an attempt to explain

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phenomena reduces the creative element of science to some sort of fortune telling. A hypothesis, if an investigation derives from one, is what makes the actual scientific inquiry meaningful. The purpose of the investigation is to find out how useful the hypothesis is in order to explain the phenomena and make predictions about them. Understanding the use and function of hypotheses is also relevant to understand the role of models in scientific inquiry (Windschitl, Thompson, & Braaten, 2008a).

A third example of NOS that could be difficult to understand without a functional language of scientific inquiry is that scientific knowledge is based on some form of empirical observations and to understand the nature of adequate evidence to support scientific claims (O'Neill & Polman, 2004). A controlled experiment is an example of a structured way of empirically deciding whether a hypothesis, as a preliminary explanation of a phenomenon, is fruitful. An experiment (as a method of inquiry) is in this sense completely different from conducting a laboratory task (as a method of teaching) in the classroom in order to make a given theoretical concept come alive. Organising inquiries around simple predictions without attempting to construct possible explanations or models will not promote reflection about the connection between claims and evidence.

A limitation of this study being based on interviews with teachers is that one must be careful when speculating about consequences for the classroom. However, this need not be so much of an issue when one considers the implications for teacher education and in particular in-service training. Nevertheless this study would benefit from an accompanying study with classroom observations to test the validity of these finding in this context and see what consequences that can be observed. One reviewer asked if a certain intertwining of pedagogical and “authentic science” interpretations of inquiry might actually be desirable in the classroom given the difference between these activities and the knowledge and goals of their participants. Our argument is that it is precisely because the activities of scientist and

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students in the classroom are so different in terms of knowledge and goals that the distinction between methods of teaching and methods of inquiry needs to be clarified. The same reviewer also suggested that if scientists were interviewed chances are that they might not always express clear distinctions in regards to the terms analysed in this paper. We agree; however, if philosophers of science and historians of science were interviewed chances are high that they would agree with our definitions. The key here is that inquiry in science education has been associated with learning goals in terms of learning about inquiry and NOS, i.e meta knowledge about the practice of science and thus the domain of scholars of science studies. Practicing scientist are normally not concerned with studying the practice of science, but rather the workings of nature. School science is not just about teaching students the results of science but also the results of science studies, that is about inquiry and NOS.

Teachers, teacher educators and authors of reform documents and curricula materials need to be aware of the ways in which traditions of school science discourse can deviate from the discourses the education is meant to introduce. If this is forgotten it is easy to talk past one another and imagine that communication is taking place simply because the same words are being used. Furthermore, the results of this study suggests that in secondary school, where there is a long tradition of laboratory work in science education, it would be helpful to clarify the distinction between *methods of teaching* and *methods of inquiry*. This is particularly important in relation to educational goals associated with inquiry to clarify what it can mean to learn about scientific inquiry and what this means for some commonly used words like hypothesis, experiment and laboratory work.

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