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Teachers' Language on Scientific Inquiry: Methods of Teaching or Methods of Inquiry?

Abstract

With a focus on the use of language related to scientific inquiry, this paper explores how 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 discussed 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.

1
2 26 Introduction

3
4 27 The call for scientific literacy as a general goal for science education has emphasised the need
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6 28 for students to develop an understanding beyond scientific concepts and skills. An
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8 29 understanding of scientific inquiry and the nature of science (NOS) is regarded as
9
10 30 fundamental to scientific literacy (Roberts, 2007). Today, many policy documents, curricula
11
12 31 materials and programmes world wide are based on the idea that inquiry should be a guiding
13
14 32 principle in science education (National Research Council (U.S.), 1996; Rocard, 2007).
15
16 33 Despite the diversity and situatedness of research on inquiry based science education (IBSE)
17
18 34 internationally, Abd-El-Khalick et al (2004) found that many themes and issues cut across
19
20 35 national boundaries – supporting the relevance of the present study.

21
22 36 The idea that inquiry should be a guiding principle in science education is not new.
23
24 37 Neither is the idea that students need to develop an understanding of what scientific inquiry is
25
26 38 and some insight into NOS (DeBoer, 1991). At the beginning of the last century Dewey wrote
27
28 39 extensively about the idea of inquiry as an organising principle in education and particularly
29
30 40 in science education (Dewey, 1910, , 1916/2004). ~~However, the~~ promotion of inquiry in
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32 41 science education has been accompanied by widespread confusion about its meaning. Almost
33
34 42 twenty years ago DeBoer (1991) concluded that teachers continue to be unclear about the
35
36 43 meaning of inquiry and confuse the idea of inquiry as a teaching strategy with inquiry as a
37
38 44 learning outcome. In Sweden, arguments about practical work in science education in terms
39
40 45 of a content to be learned or as pedagogical strategy were mixed considerably already at the
41
42 46 time of Dewey (Kaiserfeld, 1999).

43
44 47 *Research question and purpose*

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46 48 The objective of this paper is to qualitatively describe the different ways in which secondary
47
48 49 school teachers' talk about and conceptualize scientific inquiry. The purpose is to contribute
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50 50 to an understanding of teachers' reasoning in relation to inquiry in science education.
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2 51 Although this is mainly relevant for teacher educators and developers of curricula materials, it
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4 52 also points to distinctions of language use that can be both inspiring and useful for teachers
5
6 53 directly. The framing research question for this paper is: How do secondary school science
7
8 54 teachers use terms related to scientific inquiry? In the analysis we focus on the terms
9
10 55 hypothesis, experiment and laboratory work and discuss the possible implications of how
11
12 56 these terms are used in learning about scientific inquiry and NOS.

13
14
15 57 *Inquiry and nature of science*

16
17 58 According to Lederman (2004), scientific inquiry refers 'to the systematic approaches used by
18
19 59 scientists in an effort to answer their question of interest'(p. 309). In other words, there is no
20
21 60 single scientific method or algorithm. To exemplify this Lederman distinguishes between
22
23 61 descriptive, correlational and experimental research. He defines experimental research as
24
25 62 involving 'planned intervention and manipulation of variables ... in an attempt to derive
26
27 63 causal relationships' (p. 309). However, he warns that experimental research is not
28
29 64 representative for all scientific investigations and that identifying 'the scientific method' with
30
31 65 the use of controlled experiments has resulted in the promotion of a narrow and distorted view
32
33 66 of scientific inquiry.

34
35 67 Nature of Science (NOS) generally refers to the epistemology of science and science as a
36
37 68 way of knowing. Even though there is a lack of consensus among philosophers of science
38
39 69 about what NOS is and entails, this need not be an issue for K-12 instruction. Lederman
40
41 70 (2004) has described a set of NOS characteristics for which there is a reasonable level of
42
43 71 consensus and that are both relevant and teachable to K-12 students. Examples of these
44
45 72 characteristics are that students should learn the distinction between an observation and an
46
47 73 inference, that science involves the invention of explanations and that these inventions are
48
49 74 theory-laden, and that scientific knowledge relies on empirical evidence.

1
2 75 In order to facilitate discussions about NOS and scientific inquiry for educational
3
4 76 purposes, Lederman (2004) suggests the following distinction: 'it is useful to conceptualize
5
6 77 scientific inquiry as the process by which scientific knowledge is developed and, by virtue of
7
8 78 the conventions and assumptions of this process, the knowledge produced necessarily has
9
10 79 certain unavoidable characteristics (i.e. NOS)' (p. 308). This shows the close connection
11
12 80 between scientific inquiry and NOS; however, there is still a serious ambiguity as to how
13
14 81 scientific inquiry is presented in educational reforms and curricular documents. Generally
15
16 82 speaking, scientific inquiry can refer to three different ideas in education: 1) a set of skills to
17
18 83 be learned by students; 2) a cognitive understanding of the processes of inquiry, e.g. the logic
19
20 84 of a controlled experiment; and 3) a pedagogical strategy (Bybee, 2000). Lederman (2004)
21
22 85 argues that the third idea of scientific inquiry is most strongly communicated to teachers in
23
24 86 reform documents.

25
26
27 87 *Previous research*

28
29 88 The increased interest in socio-cultural perspectives on teaching and learning has been
30
31 89 accompanied by a focus on the role of language in science teaching and learning. For example
32
33 90 in his seminal work *Talking Science* Lemke (1990) suggests that 'learning science is learning
34
35 91 to talk science'. Yore, Bisanz and Hand (2003), in their review of research on language in
36
37 92 science education, make clear that any kind of inquiry or hands-on activity must be
38
39 93 complemented by an active engagement with language at all levels: speaking, listening,
40
41 94 writing and reading. Just 'doing', 'exploring' and 'experimenting' are insufficient. Scientific
42
43 95 inquiry, both in an educational and research sense, is conducted through highly developed
44
45 96 uses of language (Wellington and Osborne (2001). Carlsen (2007) has suggested that an
46
47 97 important area for further research is language as an educational outcome rather than just as a
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49 98 means. Furthermore, language-oriented activities must be accompanied by explicit
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51 99 instructions in terms of purpose, audience, style and role in science and knowledge building.
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2 100 (Crawford, Chen, & Kelly, 1997; Yore et al., 2003). Yore *et al* (2003) note that the quality
3
4 101 and quantity of oral interaction in science classrooms is generally low and unfocused.

5
6 102 Learners do not necessarily develop an understanding of inquiry as a result of
7
8 103 participating in inquiry activities (Trumbull, Bonney, & Grudens-Schuck, 2005). Similarly,
9
10 104 learners do not generally develop an understanding of NOS as a result of engaging in
11
12 105 scientific inquiry alone, regardless of whether the learners are school students, teachers or
13
14 106 scientists (Schwartz, Lederman, & Crawford, 2004). For learners to develop an understanding
15
16 107 of inquiry and NOS they also need, besides from the proper experiences, guided attention to
17
18 108 and explicit reflection on these topics (Abd-El-Khalick & Lederman, 2000). A prerequisite for
19
20 109 this is that teachers have an understanding of inquiry and NOS and such an understanding is
21
22 110 intrinsically connected to teachers having a functional language in order to be able to help
23
24 111 learners to reflect on these topics. Bartholomew, Osborne and Ratcliffe (2004) studied what
25
26 112 factors that become important when teaching 'ideas-about-science' and concluded that they
27
28 113 came to see teachers' use of discourse as particularly significant. In contrast to discursive
29
30 114 patterns that only focus on factual knowledge, patterns that invite learners to formulate
31
32 115 arguments and relate these to theory and evidence are important in modelling authentic
33
34 116 epistemic reasoning. This result was corroborated by Kelly (2007) in his review on research
35
36 117 on discourse practices in science classrooms. Because teachers direct how learners meet new
37
38 118 discourses through interaction with different forms of language from different sources and in
39
40 119 different contexts, studying their use of language is highly relevant (Leach & Scott, 2003).

41 120 Researchers have focused on teacher education and teachers' professional development to
42
43 121 improve meta-knowledge of inquiry and NOS. Pre-service science teachers often have most
44
45 122 of their experience with science from college courses. Unfortunately college courses in the
46
47 123 natural sciences rarely go into any depth in teaching about scientific inquiry and NOS. Pre-
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49 124 service teachers need first-hand experience of inquiry as well as practice in translating these
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2 125 experiences into inquiry-oriented lessons in their own future teaching (Britner & Finson,
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4 126 2005). Windschitl (2004) has described how pre-service teachers with an undergraduate
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6 127 degree in science often are well steeped in a school tradition which equates scientific inquiry
7
8 128 with “the scientific method”. However, the scientific method, as an algorithm of a few steps
9
10 129 performed in a linear fashion has been recognized as seriously misrepresenting science
11
12 130 (Rudolph, 2002). Also, Windschitl and Thompson (2006) found that pre-service teachers,
13
14 131 even with experience of authentic scientific inquiry, are not used to reflect on the role of
15
16 132 theories, models and hypotheses in scientific inquiry. To create successful courses it is
17
18 133 important to know about teacher students’ and teachers’ conceptualizations of inquiry
19
20 134 (Windschitl, Thompson, & Braaten, 2008b).

21
22 135 Teachers’ conceptualizations of inquiry are more complex than those of teacher students
23
24 136 because they often take into account wider dimensions of the school context. Nevertheless,
25
26 137 teachers are often better at articulating what inquiry is not, rather than what it is, e.g. it is not
27
28 138 following a step-by-step procedure, just reading the textbook or getting answers directly from
29
30 139 the teacher (Lotter, Harwood, & Bonner, 2006). Moreover, teachers’ use of inquiry-based
31
32 140 practices were found to be guided by four core conceptions, viz. those of science, their
33
34 141 students, effective teaching practices and the purpose of education (Lotter, Harwood, &
35
36 142 Bonner, 2007). Kang and Wallace (2005) found that teachers’ naïve epistemological beliefs,
37
38 143 but not necessarily their more sophisticated beliefs, were reflected in their use of laboratory
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40 144 activities. They suggested that this was because teachers had to negotiate their
41
42 145 epistemological beliefs as part of the teaching context and their educational goals. Evidently,
43
44 146 there are tight interconnections between teachers’ inquiry teaching practices and educational
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46 147 goals.

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48 148 Luft (2001) studied how teachers’ beliefs and practices of inquiry changed as a result of
49
50 149 participating in a professional development programme and found that inexperienced teachers

1
2 150 changed their beliefs more than their practices whereas more experienced teachers changed
3
4 151 their practices more than their beliefs. In a similar study teacher students were found to
5
6 152 acquire a deeper understanding of inquiry as a result of a pre-service course on inquiry if they
7
8 153 already had a more developed conceptualization of inquiry, whereas those who did not
9
10 154 benefited less from the course (Windschitl, 2003).

11 155 Keys and Bryan (2001) draw attention to the lack of research on inquiry practices
12
13 156 designed by teachers as opposed to by educational researchers. They recognize the need to
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15 157 develop a mutual language of overlapping cultures to frame, not only student-teacher
16
17 158 interaction, but equally importantly researcher-teacher interactions. 'Only when the voices of
18
19 159 researchers are in resonance with the voices of teachers can we begin to create harmonized
20
21 160 reform-based instruction that is enduring' (p. 642). A similar conclusion was reached by
22
23 161 Fredrichsen, Munford and Orgill (2006). They concluded that it is critical to support ways for
24
25 162 teachers and teacher educators to participate in each other's communities of practice. Most
26
27 163 studies on inquiry-based teaching have involved programmes designed by researchers and
28
29 164 taught by expert teachers; therefore more studies of how teachers ordinarily use and
30
31 165 conceptualize inquiry on their own initiative are needed. Also, since most studies involve
32
33 166 elementary and middle-school teachers and students, more studies on inquiry practices in
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35 167 secondary schools are needed (Keys & Bryan, 2001).

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38 168 Method

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41 169 *Theoretical perspective*

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43 170 With this paper we want to contribute to more efficient communication between three
44
45 171 cultures: those of teacher educators, teachers and students. To do this we emphasise that
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47 172 learning is not always unidirectional, i.e. students learning from teachers. Teachers may take
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49 173 the role as students in communications with teacher educators during in-service training and
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2 174 teacher educators may learn from teachers and students about their current realities in the
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4 175 classrooms. In this study however, we focus on teachers and note that it is their culture and
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6 176 traditions that binds these three domains together. Teachers are also students and have many
7
8 177 years of socialization in school science behind them.

9
10 178 In this paper we take a pragmatist and socio-cultural perspective on language and
11
12 179 learning. From a pragmatist perspective on language, the meaning of a word is its use and
13
14 180 function in a specific activity (Wickman & Östman, 2002b). A socio-cultural perspective on
15
16 181 learning means seeing learning as appropriation of discourse in a situated socio-historical
17
18 182 context (Wertsch, 1998). Although science is characterised by a rich synthesis of linguistic,
19
20 183 mathematical and visual representations (Lemke, 2001), conceptual learning is orchestrated
21
22 184 through a discourse that require spoken and written language. Learning to see what is relevant
23
24 185 in an investigation is reciprocally connected to and often inseparable from learning to talk
25
26 186 about it or learning the relevant language game (Bergqvist & Säljö, 1994; Wickman &
27
28 187 Östman, 2002a). A consequence of this is that what teachers are able to notice, and therefore
29
30 188 teach in science, depends on how they use language to make certain distinctions. A
31
32 189 prerequisite for teachers and students to gain access to words and concepts to talk about
33
34 190 scientific inquiry, and thereby participate in it and develop an understanding of the
35
36 191 characteristics of scientific inquiry, is that their teachers introduce and use a relevant language
37
38 192 that makes this possible.

39 193 This study is based on interview-conversations between a teacher and a
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41 194 researcher/teacher educator about the teachers' use of inquiry oriented approaches. These
42
43 195 conversations revolved around the teachers describing their own teaching approaches and it is
44
45 196 within this activity that the words analysed in this paper have meaning. By centring the
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47 197 interviews on concrete examples brought by the teachers from their own teaching units
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49 198 (books, hand outs etc.), the conversations were situated close to their actual practice. As
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1
2 199 conversations between a teacher and teacher educator the interviews also were situated within
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4 200 the broader context of teacher education, i.e. the talk analysed in these interviews is the type
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6 201 of discourse teacher educators and authors of curricular materials will have to relate to.
7

8
9 202 *The teachers: selection of participants*

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11 203 As the study was both explorative and qualitative, diversity was considered as being more
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13 204 important than a random selection of participants (Neuman, 2005). In order to achieve
14
15 205 diversity in terms of different kinds of experiences and backgrounds, we based the selection
16
17 206 on three criteria: years of experience as a teacher, equal number of men and women and
18
19 207 schools in a variety of neighbourhoods. Twelve teachers were interviewed with teaching
20
21 208 experience ranging between 5 and 30 years. The teachers' experience also varied with regard
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23 209 to in-service training with regards to inquiry practices.
24

25
26 210 *Interviews*

27
28 211 In order to obtain data on teachers' ways of describing their teaching, with a focus on inquiry
29
30 212 oriented approaches, semi-structured interviews seemed to be the most natural starting point.
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32 213 Another possibility would have been to ask a series of questions about how they use inquiry
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34 214 in their teaching and how they work with particular aspects of language in such situations.
35
36 215 Such a battery of questions would suggest certain types of answers and exclude others,
37
38 216 however, and was considered too guided – especially considering that our initial aim was to
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40 217 form an overall picture of different possible ways of talking about inquiry. Cobern and
41
42 218 Loving (2000) used a similar approach to the one adopted here in a study on teachers' enacted
43
44 219 worldviews.

45 220 In describing teachers' use of language in relation to scientific inquiry in their own
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47 221 teaching, we thought it important to connect the interviews to an authentic example that the
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49 222 teachers had used in class. We therefore asked the teachers to bring an example (e.g.
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1
2 223 instruction for lab work) from their own teaching that they thought represented an instance of
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4 224 scientific inquiry (*ett undersökande arbetsätt* in Swedish). We defined instances of scientific
5
6 225 inquiry quite loosely on purpose as 'instances in which the students themselves find out
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8 226 answers about nature through some kind of methodical study, experiment, field observations
9
10 227 or similar'. Here the idea was not to place too strict a limit on what might count as inquiry.
11
12 228 Also, by asking the teachers to bring an authentic example from their own teaching we
13
14 229 wanted to situate the interviews in the teachers' actual classrooms to avoid the inclusion of
15
16 230 too much romancing in their accounts (Kvale, 1996).

17
18 231 During the interviews the first author asked the teachers to describe their examples and
19
20 232 used a template with terms and categories that were considered important and relevant to
21
22 233 inquiry in school science (see next section: Terms to Talk about Scientific Inquiry). The
23
24 234 intention was to ask the teachers about these terms in connection with the examples they
25
26 235 supplied (Kvale, 1996). Even though a specific set of questions was not used, the following
27
28 236 questions served as a tacit guide during the interviews.

- 29
30 237 1. What terms are important in the description of inquiry as a part of the teachers'
31
32 238 practice?
33
34 239 2. What meaning do the teachers give these terms?
35
36 240 3. What function do these terms have as a part of their teaching?

37 241 This heuristic method was intended to produce an understanding of the teachers' use of
38
39 242 language without losing track of the context of school science and their own way of
40
41 243 describing their teaching. After establishing the examples and the words used by the teachers
42
43 244 during the interviews, more explicit and probing questions were asked with regard to the
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45 245 meaning and use of certain words. Care was taken, however, to stay within the limit of the
46
47 246 relevant context and example.
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1
2 247 *Terms to talk about inquiry*

3
4 248 Our purpose was to talk to the teachers about aspects of inquiry in science education in a
5
6 249 rather general way and thereby get a sense of the language of inquiry used by secondary
7
8 250 school teachers. In preparing for the interviews we did not make any particular distinction
9
10 251 between differences of inquiry in terms of research methods, teaching methods or targeted
11
12 252 knowledge in science education. Rather, our starting point was scientific inquiry as described
13
14 253 in science education research and policy documents. Even though all authentic research in the
15
16 254 natural sciences does not slot into the following structure, most academic research can be
17
18 255 described in the following way in retrospect (Chalmers, 1999; Derry, 1999; Johansson, 2003):

- 19
20 256 1. There is a starting point to inquiry. This can usually be conceived of as a question to
21
22 257 be addressed or a problem to be solved.
- 23
24 258 2. There are certain preconditions or a background against which the question or problem
25
26 259 is posed. This can be previous research, theories or models which are either used or
27
28 260 tested.
- 29
30 261 3. There are some characteristic ways in which inquiry proceeds to find answers to the
31
32 262 question or solutions to the problem. These involve the use of certain methods, a
33
34 263 striving for objectivity, and certain patterns of constructing arguments based on
35
36 264 assumptions about cause and effect, empirical evidence, predictions and Occam's
37
38 265 razor, etc.
- 39
40 266 4. The inquiry amounts to some sort of result or suggested consequences. Of paramount
41
42 267 importance in the academic research tradition is the idea of public examination of
43
44 268 research in the form of peer review. This means that to be deemed worthy, scientific
45
46 269 inquiry must result in some form of logical presentation that is intelligible to others,
47
48 270 usually in the form of a research report. In relating back to point 2, one could say that
49
50 271 the starting point and end result of scientific research is the research report.

1
2 272 Based on these reflections on scientific inquiry we formulated five categories of terms that we
3
4 273 hoped to focus on or incorporate into the conversation in a natural way during the interviews
5
6 274 in relation to the examples provided by the teachers. The first four are inspired by Lederman
7
8 275 (2004) and the fifth was added as a link to the scientific practice of peer review.

9
10 276 1. Question: guess or hypothesis

11 277 2. Method: observation, experiment, scientific, systematic, objective

12 278 3. Previous knowledge: theory, model

13
14 279 4. Logical reasoning: critical thinking, evidence, cause, prediction

15
16 280 5. Presentation: report, review, comparison with other results

17
18 281 *Data analysis*

19
20 282 Data analysis commenced with transcription of the recorded interviews. After reading through
21
22 283 these transcriptions a number of times and coding terms and sections related to inquiry, three
23
24 284 particular terms were chosen for further analysis, namely, hypothesis, experiment and
25
26 285 laboratory work (*laboration*, in Swedish) – the relevant sections of the transcriptions being
27
28 286 categorised according to these particular terms. We then studied the meanings given to them
29
30 287 by the teachers as they described their examples of inquiry units. In many cases the first
31
32 288 author drew attention to the inquiry related terms during the interview conversations and
33
34 289 asked the teachers to elaborate on them using the tacit questions mentioned earlier. Although
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36 290 the starting point for the conversations was the teaching units used by the teachers, the
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38 291 particular details of these are not necessary in order to understand the transcripts analysed in
39
40 292 this paper, as will become evident later.

41
42 293 *Results*

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44
45 294 Talking about inquiry using the terms described above in the conversations proved to be more
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47 295 difficult than we had anticipated. The teachers were more focused on the pedagogical aspects
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1
2 296 of inquiry and on learning goals in terms of exemplifying natural phenomena and motivating
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4 297 explanatory models. That is to say, the focus was on students' learning and understanding the
5
6 298 products of science as opposed to the processes of scientific inquiry.

7
8 299 The examples provided by the teachers were mainly examples of practical tasks that the
9
10 300 students worked with for one lesson or less. Educational goals expressed by the teachers
11
12 301 included exemplifying a scientific concept (e.g. density) or theory (e.g. heat expansion),
13
14 302 providing experiences of certain phenomena (e.g. earthworms), making theoretical tasks more
15
16 303 concrete and linking them to real life experiences (e.g. calculating one's pressure on the
17
18 304 floor), varying the teaching, fostering curiosity and having fun in science class. Our
19
20 305 impression was that the main emphasis in terms of knowledge goal for the students was what
21
22 306 Roberts (1982) called 'the correct explanation', and explained as 'the body of ideas accepted
23
24 307 by the scientific community at any given time'. Exemplifying scientific inquiry seemed to be
25
26 308 somewhat unusual in that it was only mentioned by two of the teachers and elaborated on by
27
28 309 one. In the latter case the teacher gave an example of learning to control variables by working
29
30 310 with a 'secret box', the content of which the students discovered by performing a variety of
31
32 311 different tests.

33
34 312 Surprisingly few of the terms used by the teachers related specifically to scientific
35
36 313 inquiry as conceptualized by us as researchers. In fact, the teachers only spontaneously
37
38 314 mentioned two of the terms on the list when talking about their examples: hypothesis and
39
40 315 laboratory report. The first author tried to probe and connect the other terms on the list to the
41
42 316 teachers' examples, sometimes asking about their use and function explicitly. One concept
43
44 317 that we thought might be particularly important was the concept of a research question and
45
46 318 that scientific inquiries start from some kind of a question (Eggen & Kauchak, 2006; National
47
48 319 Research Council (U.S.), 2000). This was explicitly addressed in all but two of the interviews,
49
50 320 often using the term 'research question'. A related question was whether this was something
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1
2 321 the teachers used when talking with their students about instances of inquiry or laboratory
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4 322 work, or in structuring their teaching. None of the teachers said anything to suggest that this
5
6 323 was an important concept in their teaching, or that 'research question' was a term they used.
7
8 324 Interestingly, one teacher returned to the idea of a research question much later, after it had
9
10 325 been brought up in the interview. She then used it in the sense of the students formulating a
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12 326 question about what they wanted to or expected to learn from a unit of self-directed study in
13
14 327 biology. Although this can be said to be related to inquiry in the general sense of the word, it
15
16 328 did not relate specifically to scientific inquiry or learning about it.

17
18 329 In this paper we focus on the analysis of three terms that illustrate a certain feature of
19
20 330 the role of language in inquiry in secondary school science instruction: hypothesis,
21
22 331 experiment and laboratory work. The function given to the term hypothesis by the teachers
23
24 332 was primarily pedagogical, i.e. inquiry as a pedagogical strategy (Bybee, 2000), which we
25
26 333 argue contrasts with its function in scientific inquiry proper. The terms experiment and
27
28 334 laboratory work were used synonymously, which also may have consequences for the
29
30 335 teaching of scientific inquiry. These three terms have a particular function when talking about
31
32 336 or during scientific inquiry and are referred to here as belonging to the category *methods of*
33
34 337 *inquiry*, but in the interview context they were used by the teachers to talk about educational
35
36 338 activities, or *methods of teaching*. This is explained in more detail in the following sections,
37
38 339 starting with the function of the term 'hypothesis'.

40 340 *Hypothesis*

41
42 341 The term 'hypothesis' was the only term that all the participants except one said they used
43
44 342 when talking to their students. In six of the interviews this term was introduced by the
45
46 343 teachers themselves when describing how they worked, and in five cases the interviewer
47
48 344 brought it up in relation to their examples. In the one case where it was not used, the example
49
50 345 contributed by the teacher was so far removed from anything resembling scientific inquiry
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1
2 346 that it was deemed irrelevant to ask about its usage. All the teachers seemed to use
3
4 347 'hypothesis' as meaning an educated guess about what might happen in a laboratory task or
5
6 348 exercise. The term was given an important role and the students were often asked to state their
7
8 349 hypothesis as a regular part of laboratory work. The function given to this term by the
9
10 350 teachers seemed to be synonymous with that of a 'prediction', although this was not a term
11
12 351 that any of the teachers volunteered. In six of the interviews, the teachers were explicitly
13
14 352 asked whether 'prediction' was a word they used, and the answer in each case was 'no'. This
15
16 353 is not very surprising given that their use of the word 'hypothesis' made 'prediction'
17
18 354 superfluous, as one of the teachers also noted.

19
20 355 In contrast to the meaning the teachers gave to 'hypothesis' in this study, this term
21
22 356 usually has a different meaning in science studies and science proper. Here a hypothesis refers
23
24 357 to a possible or preliminary explanation of an observation or phenomenon. In science it is
25
26 358 common to put a lot of effort into formulating hypotheses in such a way that they can be
27
28 359 tested through some type of investigation and thus either be refuted or gain credibility. Part of
29
30 360 the logic of hypothesis testing is that one can derive predictions based on them, which is
31
32 361 normally what is then compared with the evidence at hand, so the actual hypothesis is often
33
34 362 tested indirectly. In this way the formulating and testing of different hypotheses can be part of
35
36 363 cycles of scientific inquiry aimed at describing nature by constructing ever more satisfying
37
38 364 theories (Chalmers, 1999).

39 365 The following quotes show how the teachers described the meaning of the term
40
41 366 'hypothesis' as they wanted their students to use it – an educated guess as to what they
42
43 367 thought might happen when performing a laboratory task.

44
45 368 Interviewer: So, if someone asked, what would you say then?

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47 369 Alfred: What a hypothesis is? Well, then I would say 'what do you
48
49 370 think will happen?', 'what is your guess?' A guess.
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371 Interviewer: Yes

372 Alfred: Or an assumption.

373 -----

374 Peter: It ... in Year 7, you know, I always do these ... shall we say,

375 very trivial investigations. You boil water. So I have, they

376 get to set up a hypothesis: 'Yes, how hot does the water get?'

377 and 'How hot is it after boiling for five minutes?' and so on.

378 -----

379 Interviewer: How do you explain it [hypothesis]?

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

381 will happen?

382 The teachers use the hypothesis as a call for students to take a stand or commit themselves to

383 a guess as to what the laboratory task will result in. For instance, the result might be some

384 kind of measurement, as in the case of the temperature of boiling water (Peter), or the nature

385 or value of whatever is being studied. Alfred also adds "an assumption" to his description

386 which could be read as an assumption about a possible explanation. This is however the

387 closest statement any teacher made in this direction and based on the rest of the interview we

388 believe it is better understood as an assumption about an outcome, i.e. a prediction. Several of

389 the teachers pointed to the importance of students trying to connect to their initial hypotheses

390 when writing a laboratory report. Thus, the meaning given to 'hypothesis' continues to

391 structure the students' activities when the practical part of the laboratory work is over.

392 The hypothesis primarily has a pedagogical function in their practice as described by the

393 teachers. By that we mean that the teachers ask the students to formulate a hypothesis,

394 meaning an educated guess, before they perform a laboratory task, primarily to help the

395 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. ¶
 -----¶
 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. ¶
 -----¶
Deleted: teachers

1
2 396 | for this is that it helps the students to focus on what they are doing (Lina, below) and creates a
3
4 397 | situation that is meant to help the students to remember the science content that the laboratory
5
6 398 | task is meant to illustrate (Ann-Catherine). Furthermore, it draws the students' attention to
7
8 399 | their own preconceptions or how well they have understood or not understood the theoretical
9
10 400 | content being exemplified (Johan). Hence, it can also be seen as a way of creating conditions
11
12 401 | conducive to an aha-experience if the results are contrary to those expected.

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13
14 402 | Lina: And sometimes it can just be a way to sort of concentrate
15
16 403 | better, to think things through 'I see, yes but this should
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18 404 | probably have been blue here' or, for them to sit down, yes
19
20 405 | be forced to think a little before one gets going. Otherwise
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22 406 | they rush away to get everything and get going at once
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24 407 | without them, then they don't know what they are doing.

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.

25
26 408 | -----
27
28 409 | Ann-Catherin: If you get the wrong [answer], it doesn't matter if it didn't
29
30 410 | turn out the way you expected, because then you have given
31
32 411 | it some thought. And then the brain works so that if you have
33
34 412 | thought about it, regardless of whether you thought
35
36 413 | would happen did or didn't happen, it is easier to take in new
37
38 414 | things if you have thought about it first. But if you are
39
40 415 | completely empty it is harder to attach new things.

41 416 | -----
42
43 417 | Johan: And what does hypothesis mean? That it is your educated
44
45 418 | guess, which as a rule is almost always wrong, but it doesn't
46
47 419 | matter because that's not what is graded. But, you know,
48
49 420 | that's where they have their previous knowledge from. So

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. ¶

-----¶

1
2 421 that's where you can take your measure from and see later
3
4 422 'what did I learn from this?', 'This is what I thought ... this I
5
6 423 know, or I'm sure of then' ... or, 'this is what I know now
7
8 424 then'. It is not always one arrives at a conclusion.

9
10 425 What is made evident in these remarks is that the students are encouraged to formulate a
11
12 426 hypothesis, as an educated guess, in order to become more aware of their own learning and
13
14 427 have their own preconceptions be either challenged or confirmed. The pedagogical function is
15
16 428 also partly to control the students' attention to the task at hand. One teacher (Christian) even
17
18 429 said that he accepted a student's guess about the purpose of a laboratory task (to demonstrate
19
20 430 the presence of reduced sugars based on the chemicals given to the students) as a hypothesis.
21
22 431 His reasoning was that this demonstrated that the student had 'made the correct associations'.

23
24
25 432 *Experiment vs. laboratory work*

26
27 433 Another term that emerged as important in the conversations with the teachers was
28
29 434 'experiment' and its use as synonymous with laboratory work. The teachers seemed to use the
30
31 435 term experiment in an everyday sense as synonymous with testing, trying or doing something
32
33 436 without knowing what will happen. Therefore it is not strange that learning about experiments
34
35 437 as a conceptual content was not present in the teachers' discourse. In fact, only two of the
36
37 438 teachers in this study mentioned very briefly goals in terms of learning about scientific
38
39 439 inquiry, thus suggesting that even though teachers occasionally might have such aims, they
40
41 440 are not given a high priority. These two teachers also made no difference between the terms
42
43 441 experiment and laboratory work.

44
45 442 _____ We had not thought about distinguishing between the terms experiment and laboratory
46
47 443 work prior to the interviews and this was an insight that evolved during the study. Reflecting
48
49 444 on how the term experiment is more commonly used in science inspired us to make a
50
51 445 distinction between an experiment as a method of scientific inquiry and laboratory work as a

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1
2 446 *method of teaching science*. Although experiment has an everyday meaning that is
3
4 447 synonymous with testing *or trying*, in science the term 'experiment' is often used as an
5
6 448 abbreviation for 'controlled experiment', which is a technical term with a more precise
7
8 449 meaning. Different types of controls are used in different experimental set ups, as illustrated
9
10 450 by further specifications in the relevant terminology e.g. double-blind experiments and quasi
11
12 451 experiments. However, one could say that in essence the logic of a controlled experiment in
13
14 452 scientific inquiry is to make some change in a system and observe the result while trying to
15
16 453 control all the other variables thought to influence the result. The method is primarily useful
17
18 454 when studying causation and functions. In this context a hypothesis is a possible explanation
19
20 455 of the mechanism involved in the causation and is tested, often indirectly by deriving
21
22 456 predictions from it, through a controlled experiment (Bock & Scheibe, 2001).

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Deleted: or doing something without knowing what will happen

23
24 457 *Laboratory work on the other hand as a method of teaching science*, is a teaching
25
26 458 strategy or pedagogical activity, *and as such it can have many distinct goals* (Hofstein &
27
28 459 Lunetta, 2003). One goal could be to learn about controlled experiments as a specific type of
29
30 460 method used in scientific inquiry to answer a certain type of question, usually about causal
31
32 461 mechanisms. *However*, laboratory work could just as well be used for other educational
33
34 462 purposes e.g. to illustrate phenomena or theoretical concepts and thus focus on a particular
35
36 463 science subject matter as a learning goal.

Deleted: We thought it was important to make a distinction between an experiment

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Deleted: . This means that laboratory work in school

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38 464 The *quote* below *shows how one teacher do not distinguish between* the concepts of
39
40 465 experiment and laboratory work *and an investigation*,

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Deleted: /laboratory task

41 466 Interviewer: Do you talk about lab work then, or is it an experiment or an
42
43 467 investigation or what?

44 468 Alfred: Well, ... I, I hardly know what the difference is between
45
46 469 those three concepts [nervous laughter]. No, but I guess it is

1
2 470 a laboratory task, an investigation, an experiment, I don't

3
4 471 really know what the difference is but...

5
6 472 Interviewer: It is,

7
8 473 Alfred: Maybe there exists such a definition but ...

9
10 474 Interviewer: Well, I am not sure about that, rather, what I am interested in

11
12 475 is if it is used in any specific way. So if any difference is

13
14 476 made between such words, if it matters or not?

15
16 477 Alfred: No, not, not for me I don't think it does.

17
18 478 Interviewer: Mm [OK]

19
20 479 Alfred: No, I guess I use all three concepts a bit sloppily.

21
22 480 Interviewer: Mm [OK]

23
24 481 Alfred: I should think. Yes, I have never thought about it but yes I

25
26 482 do.

27
28 483 Alfred seemed surprised by these questions and so did Sonya, Martin and Ingrid which

29
30 484 further illustrates how these teachers do not distinguish between the terms experiment

31
32 485 and laboratory task and that this seems to be an unusual topic for them to reflect upon.

33
34 486 Interviewer: Do you talk about, eh, laboratory tasks and experiments with

35
36 487 the students as different things? Or is it the same thing, or?

37
38 488 Sonya: Yes ... that ... I don't think I have talked with them about

39
40 489 that at all actually.

41
42 490 Interviewer: What would you say a laboratory task is? And an

43
44 491 experiment? Is there any difference in school?

45
46 492 Sonya: (pause) No ... we have never thought about that. Except if

47
48 493 ... now we do an experiment or now we do a test, now we do

49
50 494 some lab work.

1
2 495 Interviewer: Mm

3
4 496 -----

5
6 497 Interviewer: Would you say that there is any difference between a
7
8 498 laboratory task and an experiment when you speak in your
9
10 499 classroom?

11
12 500 Martin: Eh, no not in my opinion. I don't know what you mean now?

13
14 501 Interviewer: Well, what you call the things you do.

15
16 502 Martin: Yes No, but I don't know. No I say laboratory tasks, but
17
18 503 they often say experiment.

19
20 504 Interviewer: OK

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22 505 Martin: But I usually don't say that. Ehm. I believe they think its
23
24 506 quite fun to do lab work, ... actually.

25
26 507 Interviewer: Mm

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28 508 -----

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29
30 509 Interviewer: Do you talk about then, since you brought it up now, I asked
31
32 510 if hypothesis was a word you needed to explain, and then, in
33
34 511 the next step? Do you talk about experiment, method,
35
36 512 observation? Do you make any...

37
38 513 Ingrid: Well no, not anything specific like that. Laboratory work is
39
40 514 what we use you know. That concept we use. We do lab
41
42 515 work, we do things so to speak, that's what it's about, and
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44 516 that's evident. 'Experiment' I don't use that much, perhaps I
45
46 517 should do that?

47 518 Another aspect of the use of the term experiment was that it seemed to be unproblematic

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48
49 519 and used in an everyday sense. In particular learning to do an experiment or an
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1
2 520 investigation was unproblematic and not something the students needed to be taught or
3
4 521 practice. Lina contributed an example that clearly could be used to illustrate a controlled
5
6 522 experiment. Her students were expected to examine earthworms to find out what sort of
7
8 523 environment they liked. They were supposed to find this out by doing two experiments
9
10 524 in which the dependent variable was where the earthworms liked to be and the
11
12 525 independent variable was either the amount of light or the degree of moisture preferred.
13
14 526 However, during the interview she talked about this in quite a different way:

15
16 527 Lina: And then, there's one [assignment] where they are supposed
17
18 528 do an experiment and investigate whether the earthworm
19
20 529 prefers light or darkness: 'write down how you did it and
21
22 530 your result in your journal', and then the idea is that they
23
24 531 shall think through how, how to best do that then. How can
25
26 532 you start to organise it? They sit together in groups of three
27
28 533 so that they can discuss. Then I guess each one should write,
29
30 534 but they can work together.

31
32 535 Interviewer: Do you talk about what an experiment is then?

33
34 536 Lina: We have done that quite a lot. When we have written lab
35
36 537 reports and such.

37 538 Interviewer: Yes

38
39 539 Lina: When we, a lot when we were in the chemistry classroom
40
41 540 and did some lab work and so.

42
43 541 Interviewer: Do you make any distinction between a laboratory task and
44
45 542 an experiment?

46
47 543 Lina: No, I don't think so. Not for them. No.

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49 544 [Later in the same interview]
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Deleted: -----¶
-----¶
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. ¶

- 1
2 545 Interviewer: Can you think of some concrete example?
3
4 546 Lina: Well...
5
6 547 Interviewer: Where you have practiced how you come up with your own
7
8 548 experiment?
9
10 549 Lina: No, that you don't have to practice.
11
12 550 Interviewer: No?
13
14 551 Lina: Come up with, they think that ...
15
16 552 Interviewer: OK
17
18 553 Lina: I mean, it is more like 'yes, can I do', sort of 'can I do it any
19
20 554 way I want to?', 'Yes, just let me know how you want to' ..
21
22 555 it ... we've studied electricity and a little of that where they
23
24 556 should connect light bulbs and they think it's great if they
25
26 557 get to do whatever they like.
27
28 558 Interviewer: Mm, of course. I thought more about if you, eh, want to
29
30 559 prepare a ... ehm, something more systematic, to collect
31
32 560 worms in a special way. Then you have to think through it a
33
34 561 little more carefully how to do it beforehand, right?
35
36 562 Lina: Mm
37
38 563 Interviewer: Perhaps ... This is a little like designing an experiment, or
39
40 564 designing an investigation you could call it.
41
42 565 Lina: Mm, a very small [investigation]...
43
44 566 In this excerpt Lina talks about the assignment as an experiment, although in the rest of our
45
46 567 conversation, and particularly when specifically asked about this, she made no distinction
47
48 568 between experiment and laboratory work or investigation. Her comment that practising how
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50 569 to design and carry out an experiment was not necessary shows that she does not talk about
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1
2 570 this as a conceptual or procedural knowledge goal indicating that scientific inquiry is
3
4 571 unproblematic. Allowing the students to 'experiment' mainly has a pedagogical function in
5
6 572 that the purpose is that the students are supposed to be kept active and think that science is
7
8 573 fun, and bring in an element of play.

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10 574 As a further illustration, Catherine in the quote below, seems to talk about an experiment
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12 575 as unproblematic and does not reason about it in terms of something to be conceptually
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14 576 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.

15
16 577 Interviewer: Mm. And then you mentioned hypothesis.

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18 578 Catherine: Yes.

19
20 579 Interviewer: Apart from that this is something different than just 'atom'
21
22 580 and 'beaker', those are more like specific, 'hypothesis' is
23
24 581 something that can occur in any natural science subject.

25
26 582 Catherine: Yes.

27
28 583 Interviewer: Other subjects too, it doesn't have to be natural science ...

29
30 584 Catherine: Mm.

31
32 585 Interviewer: Or also experiment, observation, have you also discussed
33
34 586 such things?

35
36 587 Catherine: Ehm... No ... Experiment, yes, maybe that I have explained
37
38 588 that word yes ...

39
40 589 Interviewer: Now you are thinking about Year 6?

41
42 590 Catherine: Yes, exactly, now I'm thinking about Year 6.

43
44 591 Interviewer: And what about Years 7, 8 and 9?

45
46 592 Catherine: Then you take it for granted that they should know what this
47
48 593 word is, experiment, what it stands for.

1
2 594 Interviewer: Mhm, Do you make any difference between laboratory work
3
4 595 [laborationer] and experiments like that?
5
6 596 Catherine: Ehm, no I can't say that I make any difference.
7
8 597 Catherin does not seem to think the concept of an experiment merits special attention, yet at
9
10 598 the same time the students are expected to understand and be familiar with what an
11
12 599 experiment is since they use it in order to learn other things. As became evident in the rest of
13
14 600 the conversation, Catherine was not clear about the meaning of a controlled experiment.
15
16 601 These excerpts from the interviews with Alfred, Sonya, Martin, Lina and Catherine
17
18 602 show that for them the terms laboratory work and experiment are synonymous and indicate
19
20 603 that they do not reason about scientific inquiry in terms of a conceptual targeted knowledge.
21
22 604 We do not claim that the teachers, when they use the terms experiment or laboratory work,
23
24 605 "actually have in mind" either a pedagogical strategy or a particular research method such as a
25
26 606 controlled experiment, although it is possible. The point is that there is nothing to suggest that
27
28 607 they differentiate between the notions of an experiment and laboratory work in terms of
29
30 608 methods of teaching or methods of inquiry when they talk about their teaching. This is a
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32 609 distinction we have introduced to make sense of how and why the teachers mix these terms
33
34 610 and seem so perplexed when asked about them. From our theoretical perspective the meaning
35
36 611 of a word is in its use in a particular situation. Thus, in the situation of a teacher talking with a
37
38 612 teacher educator and researcher about inquiry the terms experiment and laboratory work have
39
40 613 the same function and meaning. Furthermore, if these conversations also reflect how these
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42 614 teachers talk with their students, the students' possibilities to learn about the characteristics of
43
44 615 certain methods of inquiry are thus lost in an unreflective use of everyday discourse.

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same thing, or?Deleted: 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. ¶

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 it's quite fun to
do lab work, ... actually.¶

Interviewer: . Mm¶

The

Deleted: Ingrid,

Deleted: , Lina, Sonya

Deleted: Martin

Deleted: We suggest that this is
associated with a conflation of two
categories of methods, namely, *methods
of teaching* and *methods of inquiry*, as
part of an emphasis on teaching the right
explanation.Deleted: only two of the teachers
mentioned very briefly goals in terms of
learning about scientific inquiry, thus
suggesting that even though they
occasionally might have such aims, they
are not given very high priority. If

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talkingDeleted: What we seem to find here is
a lack of distinction between the activities
of teaching and the activities of research,
which results in some of the goals of
science education being missed out.

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1
2 616 Discussion

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4
5 617 *Summary of results*

6
7 618 In the analysis we have tried to show how use of the terms hypothesis, experiment and
8
9 619 laboratory work mix two categories of methods, namely, *methods of teaching* and *methods of*
10
11 620 *inquiry*. In terms of knowledge goals associated with scientific inquiry, this means a
12
13 621 conflation of means and ends. In other words, while 'hypothesis' and 'experiment' are used in
14
15 622 a way that aims at achieving learning goals associated with science content as a product, e.g.
16
17 623 theories, facts and models, the possibilities of developing a language to both talk and learn
18
19 624 *about* scientific inquiry and NOS seem to be limited.

20
21 625 We began with the assumption that in order to develop scientific literacy it is necessary
22
23 626 to have a grasp of how theories, knowledge claims, definitions and explanatory models are
24
25 627 developed in science. Learning about scientific inquiry can, for example, mean learning
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27 628 something about the rationale and logic of scientific research methods. It can mean to
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29 629 understand that scientific inquiries begin with a question and that a hypothesis is a
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31 630 preliminary answer to that question or explanation of the phenomenon of study, often of
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33 631 causal nature, and that a controlled experiment is a special method or type of investigation.

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35 632 The result presented here suggests that in their teaching the interviewed teachers do not
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37 633 reason about understanding scientific inquiry as conceptual knowledge. Instead they appear to
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39 634 focus almost exclusively on knowledge goals in terms of learning the products of science and
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41 635 the use of this knowledge. In order to achieve this aim they use certain *methods of teaching*,
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43 636 which they describe as laboratory work, laboratory tasks and investigations or experiments
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45 637 without differentiation. The students are asked to formulate hypotheses (guess the answer)
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47 638 with the purpose that they learn and remember the correct explanation. One way of clarifying
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49 639 the use of these terms in relation to scientific inquiry as targeted knowledge in school is to
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51 640 differentiate between the categories of *methods of teaching* and *methods of inquiry*. In

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1
2 641 focusing on developing knowledge about the products of science, terms like experiment and
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4 642 hypothesis are subsumed under this purpose and functionally fall into the category of *methods*
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6 643 *of teaching*. If the learning of scientific concepts and theories was the only objective of the
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8 644 education this would not be a problem. But in order to learn about scientific inquiry these
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10 645 terms are needed conceptually as a part of the category of *methods of inquiry* to be able to
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12 646 learn the relevant distinctions of this aim. This would be an example of language as an
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14 647 educational outcome rather than just as a means (Carlsen, 2007). Further research is needed to
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16 648 establish exactly what teachers' language use is in the classroom and what it means for
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18 649 students' learning about inquiry and NOS.

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21 650 *Possible explanations*

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23 651 Language is dynamic and subject to constant change. Words and expressions often evolve in
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25 652 use and meanings change over time. In some cases the same word may have different
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27 653 meanings and connotations in different activities simultaneously, as the present study
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29 654 exemplifies. This is nothing new, and asking why a particular word is used in a certain way
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31 655 may not prove very fruitful, since this often depends on multiple factors and contingencies
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33 656 and whether the question demands a causal or teleological explanation. However, it is
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35 657 interesting to note that many science teachers are themselves the products of an 'archetypal
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37 658 education which has largely ignored the epistemic base and nature of its own discipline' (p.
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39 659 659) (Bartholomew et al., 2004). Traditionally, higher education courses in natural science
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41 660 devote very little time and resources to reflection about inquiry and the nature of science.
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43 661 Why the teachers in this study use the terms hypothesis and experiment in an everyday type of
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45 662 language game may therefore reflect the way they have been taught natural sciences at
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47 663 university level. To study the correlation between teachers' educational background and
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49 664 experience with inquiry would have to be another study. However, we can note that the terms
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51 665 analyzed in this paper was used in a very similar way by teachers with highly diverse

Deleted: teachers

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2 666 educational backgrounds. While earlier studies have shown an emphasis on the correct
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4 667 explanation in teacher education is important (Lager-Nyqvist, 2003), further studies are
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6 668 needed to ascertain what this might mean in terms of language use.
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9 669 *Possible implications*

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11 670 An interesting question relates to how using the terms analyzed here in particular ways
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13 671 restrains or affords reflection and understanding (Wertsch, 1998). In this study this amounts
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15 672 to asking how these terms relate to educational goals associated with inquiry. The conflation
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17 673 between terms relating to *methods of inquiry* versus *methods of teaching* can have
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19 674 problematic consequences. For example, the development of controlled experiments has been
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21 675 part of the development of science since the beginning of the scientific revolution and has
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23 676 been enormously significant (Chalmers, 1999). However, exactly what it is, what it is for or
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25 677 how it can be done it is not immediately obvious to someone new to science. One of the
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27 678 teachers said that he did not expect his students to arrive at Newton's theory of gravity simply
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29 679 by playing around with apples. Nevertheless, the way that he and most of the other teachers
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31 680 talked about scientific inquiry as a pedagogical activity, unproblematic in terms of conceptual
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33 681 learning, suggest that the students are expected to invent the principles of a controlled
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35 682 experiment themselves by being 'given freedom to explore stuff'. Even though one of the
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37 683 teachers (Ann-Catherin) gave an example of teaching the control of variables, she didn't talk
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39 684 about this as a controlled experiment, and seemed to have difficulty in finding words to
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41 685 articulate it.

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43 686 A prerequisite for learning in institutional practices such as school science is that
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45 687 learners are given access to a relevant discourse. What learners are given an opportunity to
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47 688 distinguish depends on how language is used in reflecting on inquiry. This is so whether the
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49 689 learners are students, teachers or scientists. Terms such as 'hypothesis' and 'experiment' used
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51 690 to talk about and during examples of scientific inquiry are parts of such a discourse. Students
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2 691 learn about scientific inquiry by gaining access to such words, using them in action, and
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4 692 communicating and thinking with them in contexts in which they have consequences and
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6 693 become meaningful. If the term hypothesis is treated during inquiry oriented approaches in
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8 694 the way this study suggests, then an important dimension for learning about scientific inquiry
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10 695 is not available to explicitly reflect upon as part of the discourse the students are being
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12 696 introduced to. Some teachers clearly expressed that they considered it important that the
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14 697 students learn the correct language of science and use words in their correct scientific sense.
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16 698 This concern about teaching students the correct use of scientific terms contrasted sharply
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18 699 with the teachers' unreflective and everyday use of language in relation to scientific inquiry.

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20 700 In addition to making communication about scientific inquiry more difficult, conflating
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22 701 the categories *methods of teaching* and *methods of inquiry* may also be an obstacle to an
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24 702 understanding of NOS. Let's have a look at what this might mean for some of the
25
26 703 characteristics of NOS Lederman (2007) has defined as important for K-12 instruction. One
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28 704 aspect of NOS that may be more difficult to understand is the distinction between an
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30 705 observation and an inference. Based on how the teachers in this study used the term
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32 706 hypothesis, the students are left with observing and "guessing what will happen". However,
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34 707 making inferences from observations often entails reference to the causal propositions stated
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36 708 in a proper hypothesis.

37 709 A second example of NOS is that scientific knowledge is theory-laden. This is
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39 710 associated with understanding the creative dimension involved in formulating hypotheses as
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41 711 possible explanations. The formulation of hypotheses and the associated design of
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43 712 investigations to test their validity and reliability are based on theoretical assumptions and the
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45 713 results of previous inquiries, which is the essence of theory-ladenness. As Lederman (2007)
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47 714 puts it, 'science involves the invention of explanations'. An exclusive focus on predictions at
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49 715 the cost of understanding the role and function of hypotheses as an attempt to explain
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2 716 phenomena reduces the creative element of science to some sort of fortune telling. A
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4 717 hypothesis, if an investigation derives from one, is what makes the actual scientific inquiry
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6 718 meaningful. The purpose of the investigation is to find out how useful the hypothesis is in
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8 719 order to explain the phenomena and make predictions about them. Understanding the use and
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10 720 function of hypotheses is also relevant to understand the role of models in scientific inquiry
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12 721 (Windschitl, Thompson, & Braaten, 2008a).

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14 722 A third example of NOS that could be difficult to understand without a functional
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16 723 language of scientific inquiry is that scientific knowledge is based on some form of empirical
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18 724 observations and to understand the nature of adequate evidence to support scientific claims
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20 725 (O'Neill & Polman, 2004). A controlled experiment is an example of a structured way of
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22 726 empirically deciding whether a hypothesis, as a preliminary explanation of a phenomenon, is
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24 727 fruitful. An experiment (as a method of inquiry) is in this sense completely different from
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26 728 conducting a laboratory task (as a method of teaching) in the classroom in order to make a
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28 729 given theoretical concept come alive. Organising inquiries around simple predictions without
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30 730 attempting to construct possible explanations or models will not promote reflection about the
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32 731 connection between claims and evidence.

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34 732 A limitation of this study being based on interviews with teachers is that one must be
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36 733 careful when speculating about consequences for the classroom. However, this need not be so
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38 734 much of an issue when one considers the implications for teacher education and in particular
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40 735 in-service training. Nevertheless this study would benefit from an accompanying study with
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42 736 classroom observations to test the validity of these finding in this context and see what
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44 737 consequences that can be observed. One reviewer asked if a certain intertwining of
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46 738 pedagogical and “authentic science” interpretations of inquiry might actually be desirable in
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48 739 the classroom given the difference between these activities and the knowledge and goals of
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50 740 their participants. Our argument is that it is precisely because the activities of scientist and

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2 741 students in the classroom are so different in terms of knowledge and goals that the distinction
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4 742 between methods of teaching and methods of inquiry needs to be clarified. The same reviewer
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6 743 also suggested that if scientists were interviewed chances are that they might not always
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8 744 express clear distinctions in regards to the terms analysed in this paper. We agree; however, if
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10 745 philosophers of science and historians of science were interviewed chances are high that they
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12 746 would agree with our definitions. The key here is that inquiry in science education has been
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14 747 associated with learning goals in terms of learning about inquiry and NOS, i.e meta
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16 748 knowledge about the practice of science and thus the domain of scholars of science studies.
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18 749 Practicing scientist are normally not concerned with studying the practice of science, but
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20 750 rather the workings of nature. School science is not just about teaching students the results of
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22 751 science but also the results of science studies, that is about inquiry and NOS.

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24 752 Teachers, teacher educators and authors of reform documents and curricula materials
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26 753 need to be aware of the ways in which traditions of school science discourse can deviate from
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28 754 the discourses the education is meant to introduce. If this is forgotten it is easy to talk past one
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30 755 another and imagine that communication is taking place simply because the same words are
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32 756 being used. Furthermore, the results of this study suggests that in secondary school, where
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34 757 there is a long tradition of laboratory work in science education, it would be helpful to clarify
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36 758 the distinction between *methods of teaching* and *methods of inquiry*. This is particularly
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38 759 important in relation to educational goals associated with inquiry to clarify what it can mean
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40 760 to learn about scientific inquiry and what this means for some commonly used words like
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42 761 hypothesis, experiment and laboratory work.

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