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Secondary science teachers' selective traditions and examples of inquiry-oriented approaches

Abstract

This paper describes aspects of the existing tradition of practical work in secondary science education in Sweden, with a focus on inquiry-oriented teaching approaches. Twelve secondary science teachers were interviewed and asked to describe examples of their own teaching practices that they believed constituted inquiry-oriented teaching. The descriptions are analysed in relation to key components of inquiry as conceptualised in the science education literature. In addition, the teachers' way of talking about their own teaching in relation to inquiry is described and analysed. The results show a wide variety of teaching approaches that are associated with inquiry in different ways. Although inquiry is valued by many teachers, it is also problematic. We discuss the nature of the problems associated with inquiry by the teachers and the possible consequences of these for teacher education, in-service training and curriculum development.

Introduction

Inquiry has been promoted as a guiding concept of science education for more than one hundred years and continues to be so (DeBoer, 1991; I.A.P., 2005; National Research Council (U.S.), 1996; Rocard, 2007). In Sweden, the Royal Academy of Science initiated a school development programme in 1996 called Science and Technology for All (NTA) that is widely used today in Swedish primary schools and secondary schools for which it is being further developed. NTA is inspired by a curricular material developed in the US called Science and Technology for Children (STC), in response to the US National Standards call for Inquiry Based Science Education (IBSE) (www.nta.se). Given the level of efforts and funds dedicated to promoting inquiry, it is relevant to examine what inquiry and related approaches mean to Swedish teachers. Insights gained from studying inquiry in Swedish schools can also be relevant for science education in other countries, as issues related to inquiry are similar across many countries (Abd-El-Khalick et al., 2004).

The conditions and constraints for IBSE have attracted the attention of researchers for a long time. While some research has provided exemplars of successful teaching and learning through inquiry (Crawford, 2000), most reports have focused on identifying obstacles to reaching policy intentions (Anderson, 2007; Hume & Coll, 2008; Lederman, 2004; Rowell & Ebbers, 2004) and on teacher education (Windschitl, Thompson, & Braaten, 2008). Although widely discussed and researched in the US and UK, there is no well known equivalent of the expressions "inquiry" and "IBSE" in Sweden, which is part of the reason for this study. However, practical work in science education was introduced in Swedish upper secondary schools in approximately 1900 (Kaiserfeld, 1999). Löfdahl (1987) analysed physics laboratory tasks in secondary and upper secondary schools in Sweden between 1962 and 1980 and found almost no examples of inquiry, as the term is used in this paper. Hult (2000) concluded that closed as opposed to open-ended laboratory work is the rule in higher education. More recently, Högström, Ottander and Benkert (2005) interviewed eleven secondary teachers about their goals with laboratory work in science. They found that the most common goals included confirming theory and creating a need and motivation to learn theory.

The development of curriculum materials and reform efforts has shown that for these to contribute positively, teachers' voices and existing school cultures must be taken into account (Keys & Bryan, 2001; Trumbull, Bonney, & Grudens-Schuck, 2005). Otherwise, school development projects may be hindered by participants holding different, unarticulated and unchallenged assumptions about key issues (Fredrichsen, Munford, & Orgill, 2006; Trumbull et al., 2005). Research into the history of school subjects shows that different selective traditions develop, which can be understood in terms of how content and teaching methods are habitually selected (Sandell, Öhman, Östman, Billingham, & Lindman, 2005; Williams, 1973). Like other established traditions, selective traditions are often largely unexamined by its members (Dewey, 1930). This may result in new influences such as a new curriculum or curricular material being interpreted and used within the existing tradition, and thus transformed into something old and familiar. Avoiding this requires active reflection on the existing tradition, and a prerequisite for this is that the traditions are first made explicit. In addition, teachers may already have functional teaching approaches relative to the aforementioned policy documents. Nonetheless, according to Keys and Byran (2001), there is a lack of research on inquiry-oriented approaches that are designed and used by teachers without the involvement of educational researchers. The present study is an attempt to make the existing tradition of practical work explicit in respect to key dimensions of inquiry described in the science education literature. It aims to clarify the debate on curriculum development as well as assist teachers to discuss their own teaching by introducing a taxonomy of instructional approaches. In particular, we have focused on the following three research questions:

1. What do secondary science teachers describe as their own examples of inquiry-oriented teaching approaches?
2. What affordances, problems and contrasts do the teachers describe in relation to inquiry-oriented teaching approaches?
3. How are these examples related to conceptualisations of inquiry in the science education literature?

Method

Twelve teachers were asked to bring an example from their own teaching that they thought represented an inquiry-oriented approach (IOA) (*ett undersökande arbetssätt* in Swedish) for teaching science. The instances of IOA were rather loosely defined intentionally as instances in which the students themselves find out answers about nature through some kind of methodical study, experiment, field observations or similar. The idea was to avoid placing too many constraints on what might count as inquiry. Furthermore, the reason for asking the teachers to bring an authentic example from their own teaching was to situate the interviews in the teachers' actual classrooms in order to avoid the inclusion of too much romancing in their accounts (Kvale, 1996).

Interviews

To obtain data on the teachers' examples of IOA, semi-structured interviews were used. To ask a predefined series of questions about how they use inquiry in their teaching would suggest certain types of answers and exclude others; this was considered too guided - especially since the aim was to obtain a broad description of the existing tradition. Cobern and Loving (2000) used a similar approach to the one adopted here in a study on teachers' enacted worldviews.

The interviews took place at each teacher's school. 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 the section *Inquiry and learning outcome emphases*). 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 is the example about?
2. How is this example motivated as a part of this teacher's teaching?
3. What are the students supposed to learn?
4. How is this example related to key dimensions of IOA?

This heuristic method was intended to produce an understanding of the teachers' examples without losing track of the context of school science and their own way of describing their teaching. However, as the researcher focused on aspects of inquiry during the interviews, in terms of both scientific investigations and as a teaching approach, some teachers recalled additional examples that they believed were more relevant.

The recorded interviews were transcribed and then condensed into first-person narratives with a focus on the research questions of this study. Care was taken to retain the original wording of the teachers during the interviews, while also making it a more readable text. In some narrative quotes the wording may seem slightly unusual. This is due to the fact that they are an attempt to stay close to the spoken language of the interview setting, and is not an artefact of the translation into English. The narratives were read by the teachers and then revised and edited according to their suggestions. This increased the validity by enabling the teachers to omit errors and ensuring that these individuals felt that they could stand for the statements.

Participants

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

Analytical framework

The term "inquiry" has been used to refer to at least three different ideas within science education: a set of skills to be learned by students, a conceptual knowledge of the characteristics of doing science and a pedagogical strategy (Bybee, 2000). Below, we describe key dimensions of inquiry as conceptualised in influential policy documents, curricula and the science education literature in terms of learning outcomes and instructional approaches.

Inquiry and Learning Outcome Emphases

Inquiry as a learning outcome is one of many learning outcomes specified by curricula in various forms and with different emphases. The Swedish national curriculum for secondary school science includes learning outcomes in terms of knowledge about scientific investigations as well as abilities to plan and conduct scientific investigations (Swedish National Agency for Education, 2009). In this study we use three categories of intended learning outcomes to analyse the examples discussed with the teachers. The first two are specific to inquiry and IBSE, while the third is generic in science education.

A) Learning to do inquiry
B) Learning about inquiry
C) Learning science subject matter

Learning to do inquiry (A) includes a set of skills that students need to master to "do science", but it also goes beyond mere process skills. Learning to do inquiry also means combining these processes with scientific knowledge, reasoning and critical thinking to develop scientific knowledge (Lederman, 2004). We choose to focus on only two specific aspect that have been described as fundamental by influential policy documents, teacher handbooks and educational research: 1) learning to pose questions and formulate hypotheses that can be investigated in a scientific manner and 2) learning to design, plan and carry out a scientific investigation in relation to a research question or hypothesis (Eggen & Kauchak, 2006; Lederman, 2004; National Research Council (U.S.), 2000).

Learning about inquiry (B) includes knowing how scientific knowledge is developed. Knowledge about inquiry would, for example, include knowing that scientific investigations are derived from a question or hypothesis, and that answering scientific questions involves empirical data. It also includes understanding that there is no single scientific method, that questions guide the methods used by scientists and that these vary greatly. Knowledge about inquiry would, for example, also include that control of variables (i.e. a controlled experiment) is a particular scientific method used to study causality, and that this differs from studying correlations (Lederman, 2004). Knowledge in both category A and B involves acquiring a language in order to talk and communicate about investigations and their results. Knowledge about inquiry may be useful for doing inquiry and are not merely propositions to be remembered.

Learning science subject matter (C) basically refers to learning the conceptual products of science - the textbook explanations, models and concepts. This learning outcome is generic and not connected to IBSE in any specific way. The subject matter of a science curriculum can be structured in different ways (Roberts, 1982). In this paper, we group all categories of curricular emphases or goals not explicitly associated with inquiry in category C, including e.g. learning about socio-scientific issues.

Inquiry as an Instructional Approach

To describe the teachers' examples and differentiate types of instructional approaches, we constructed a taxonomy of instructional approaches (Table 1). This is inspired by the work of Schwab (1962) and Domin (1999), and it is based on the division of a scientific investigation into three parts: question, method and results. In investigations as instructional activities, these parts can either be open or given. Schwab used these to define the concept of degrees of freedom from 0 to 3 for practical work, and Domin used a similar scheme to define the instructional approaches: inquiry, guided-inquiry/discovery, expository and problem-based. Below, we comment on each instructional approach.

Table 1. Taxonomy of instructional approaches based on the dimensions of question/method/ result that can be either open (O) or given (X)

Degrees of freedom	Type of instructional approach	Question / Problem	Method	Answer / Result
0	Expository	X	X	X
0	Discovery	X	X	X
1	Problem-Based	X	O	X
1	Guided Inquiry	X	X	O
2	Inquiry	X	O	O
3	Open Inquiry	O	O	O

Expository Instruction: This is probably the most common laboratory instructional approach in which students follow directions to reach a predetermined outcome, e.g. measuring a natural constant in physics. This is often done by using a "cook book" style of instruction.

Discovery Instruction: This approach has the same degree of freedom as *Expository Instruction,* but the difference lies in how it is staged by the teacher - the dramaturgy one may say. The teacher leads the students on so they feel as if they have "discovered" a particular phenomena or arrived at a specific notion or need for a specific notion. Here we use the term "discovery" differently from Domin (1999) who equated it with "guided inquiry".

Guided Inquiry/Inquiry/Open Inquiry Instruction: The main characteristic of these approaches is that they are framed by some sort of question for which an answer cannot readily be found in a textbook. In *Inquiry Instruction,* the question is given by the teacher, whereas in *Guided Inquiry Instruction,* both the question and the method are provided by the teacher. In *Open Inquiry,* an important part is to formulate a question that can be investigated.

Problem-Based Instruction: The main difference from the various types of inquiry is that the question and result melt together in the formulation of a problem to be solved. There are usually different ways or methods of solving the problem.

Sometimes concepts like "inquiry learning" or "discovery learning" are used to refer to some vaguely defined psychological process of learning. What is usually meant is "learning when doing inquiry" or "learning when making discoveries"; therefore, we feel that it is more honest and less confusing in this context to reserve terms like "inquiry" and "discovery" to refer to instructional approaches rather than to modes of learning.

Obviously, this simple taxonomy is a very crude map of different types of instructional approaches. The different types of instruction may follow each other in a sequence of teaching with different emphases. Moving between different approaches can be thought of as more or less continuous or sometimes in terms of discrete steps. However, its usefulness lies in its simplicity as a tool for analysing teaching approaches. The taxonomy was applied to all of the major examples of teaching units discussed during the interviews. Each interview was read by the two first authors to reach a consensus about the coding. The application was straightforward with few exceptions (see *Results*).

Teachers' Own Descriptions of IOA

In addition to using the taxonomy of instructional approaches, two methods of analysing the teachers' own ways of describing IOA were used. First, the narrative summaries were coded into three categories: statements referring to positive associations with IOA, problems associated with IOA and descriptions of instructional approaches. Positive and problematic associations with IOA were summarised and then sorted into secondary categorisations consisting of groups of statements that had some features in common. This led to a re-evaluation of some statements as either positive, problematic or neither. All of the narratives included statements that were relevant to these categories.

Secondly, repeated readings of the narratives and the original interview transcripts suggested that the descriptions of instructional approaches could be coded into two subcategories: instructional approaches associated with IOA and those in contrast to these. Nine out of the twelve narratives contained descriptions of instructional approaches, which supported this subcategorisation. For the remaining three interviews, the original transcripts were reread to determine if any descriptions of instructional approaches had been missed in the compilation of the narratives. However, none were found. The descriptive statements were isolated, and from these, a table of descriptors of instructional approaches was compiled.

Results

Teachers' Outcome Emphases and Instructional Approaches

Here, 6 of the 18 main examples discussed during the interviews are presented in the format of condensed narratives. They are chosen to represent the range of the different types of examples encountered. Each example is commented on with particular reference to the learning outcomes A, B and C, (i.e. learning to do inquiry, learning about inquiry and learning through inquiry), and instructional approaches. The names of the teachers are pseudonyms.

> *Christian:* Two laboratory tasks that we recently did [in grade 8] had to do with how you can recognise starch and how the saliva affects starch in the food. The students worked with each laboratory task for perhaps 20 minutes. What I want them to learn is that you can show the presence of starch with iodine, and reduced sugars with Trommer's test, and that starch is decomposed into sugar by a substance in the saliva called amylase. It is also slightly connected to biochemistry. The laboratory tasks are not structured around a research question but are more like recipes to give the students a map to go by, a base on which to stand. So I want them to learn to draw conclusions from the tests and even be able to go home and do it themselves. […] An advantage of having laboratory tasks with this recipe-like structure with a list of items A, B, C, D is that even the somewhat weaker students can follow along. Even a student who has difficulties with chemistry can then perform a laboratory task. A correctly performed laboratory task actually teaches the student quite a lot.

Christian's lessons are almost always centred on the students performing short laboratory tasks in the form of recipes that never extend beyond one class period. The focus in this example is to teach the students about starch, sugars and their reaction with the enzyme amylase, i.e. on science subject matter. This is an example of *Expository Instruction*. At the same time, students are learning to perform a certain test and Christian also talks about wanting them to be able to conduct tests on their own. However, when asked about learning to do inquiry and learning about inquiry, there was nothing to suggest that these were explicit teaching aims in this example or in his instruction in general. Also, as it shall be noted further on, Christian expressed a rather negative attitude toward IOA.

The next example, provided by Johan, was raised in connection with the problem of motivating students to engage in laboratory activities.

> *Johan:* We have many discussions about the natural scientific way of investigating; that it is important to be meticulous when doing lab work, and to do it thoroughly and carefully. We have, for example, done a laboratory task [in grade 7] in which you mix 50 ml of water with 50 ml

> of methanol and discover that you don't get 100ml. This leads to a lot of discussions and why they have to learn to do lab work carefully. It can take several class periods to sort out, and it has led to us mixing sand and peas because that really makes it obvious that you don't get the same volume. Then you get in to this scientific stuff, and that you have to do more tests.

Here, the students are expected to realise that it is important to do laboratory work carefully. Johan refers to two required characteristics for an investigation to be considered scientific: that it is done meticulously and that the same test is performed several times. Although there are traces here of learning to do inquiry and learning about inquiry, the main teaching goal with this activity is to learn about the relative size of molecules. The students are led to a "discovery" which at first appears to be contrary to common sense. Thus, this is an example of *Discovery Instruction*.

Ann-Catherin initially also provided an example in which students were led to make a "discovery" of the phenomena of heat expansion of water. Upon continuous probing for inquiry-related topics, she recalled the following example.

> *Ann-Catherin:* Last fall, we worked in a more focused manner [in grade 7] with the natural scientific way of working in connection with studying environmental issues. Then we brought up things like the fact that you only vary one thing at a time, because otherwise you don't know what you measure. We did this with secret boxes and an exercise in which you are supposed to find out what is inside a lump of clay. Then its like, that what is in the box is what the majority agrees upon because that is how it is done when you do research. So we calculate the percentage. Then the students protest and say that it is not a math class. But then I explain that this is the sort of thing you use math for. Eventually, someone usually becomes so frustrated by not knowing that they open the box.

In this case, the question, "What is in the secret box?", is given and the students are also taught a method, i.e. controlling variables, in order to investigate and attempt to answer the question. This can be thought of as an example of *Guided Inquiry Instruction*. However, it is not really genuine, given that there is a single correct answer that the teacher knows and keeps from the students. This was one of two examples of the entire 18 with an explicit aim to teach about inquiry and practice doing inquiry in a rudimentary sense. Ann-Catherin explained that she used the Secret Box exercise as a model example to refer back to when discussing other instances of laboratory work with her students.

Another teacher, Lina, also described an example that can be labelled *Guided Inquiry Instruction*. In this case, the students (grade 9) collected samples of snow from different locations around the school and measured the water's pH level. The question and method were provided by the teacher (although the students had some choice where to collect samples). However, as neither the students nor the teacher knew exactly what they would find it is more genuine than the example by Ann-Catherin. Also here the focus is on teaching science through inquiry, i.e. knowledge outcome of type C. Lina also described the following example:

> *Lina:* Today, we began with a task [in grade 7] in which the students are going to study worms and they got to run out and dig for worms. They were really excited. The purpose is for them to find out about the anatomy of earthworms. They are also to do an experiment and investigate if the worms prefer light or darkness. The idea is for them to think about the best way to do that, how you can organise it. They work in groups of three, but each one then writes their own laboratory report. I want them to be able to do a little bit as they please here, which is ok because there are no dangerous things involved as is sometimes the case in chemistry. Hopefully, they will learn that worms are attracted to darkness and moisture. The goal with this particular exercise was not to learn how to conduct an experiment, but rather for them to feel a little freer and realise that you can do it in many different ways.

This example resembles some of the exemplars of inquiry teaching found in the science education literature (National Research Council (U.S.), 2000). Lina has introduced a topic and given the students the task of investigating a specific question. However, when asked about the role of a research question in this and other instances of IOA, she does not appear to have reflected about this. The targeted knowledge is focused on learning about worms and the classification of animals, not about inquiry or learning to do inquiry. Therefore, this is also an example of learning science subject matter (C) through inquiry as a pedagogical method used to inspire. However, as an instructional approach, it can be labelled *Inquiry Instruction,* in line with our taxonomy.

The only example that could be called *Open Inquiry Instruction* was described by Peter. Although he had initially brought another example, he subsequently recalled this one as the interview progressed.

> *Peter:* One example of the students conducting their own investigations is what we are doing right now when the year-nine students investigate different brands of kitchen paper and toilet paper. So the question is; "Which paper do you think is the best?" They are to investigate the papers based on what they come up with and want to find out, asking their own questions. Some groups only investigate the suction ability and feel that that is enough, whereas others begin to think about durability, resistance to pull, appearance and design. They consider many different aspects. Then they get to devise their own method to attempt to answer the question. The degree of freedom is high. They get to plan, structure and perform the actual investigation on their own, and then analyse the results. We take about one class period for the planning and one period for carrying out the investigation, then they get to write a laboratory report as homework. The students think it is a lot of fun. The purpose of this exercise is, among other things, for them to learn to investigate, and the natural scientific way. That they actually learn to be curious and investigate something. It can, for example, involve looking at extreme relationships. Then it is also about learning to describe what happens based on existing models and concepts. Doing your own investigations is also about learning to think critically.

Peter's example is the finale of a unit on the properties of matter. It is the second of two examples with explicit aims in terms of learning about inquiry, although it is rather vague in this case. The investigation is centred on a general question or theme, and the students develop their own research questions and also design, plan and carry out investigations in groups. It resembles Ann-Catherin's example with the Secret Box, in that it appears to have a rather weak connection to any science content, but this was not probed sufficiently during the interview to know for certain. Peter explicitly states that the aim is for the students to learn to investigate in a scientific way. However, it was not clear if they had received any training or instruction in how to formulate researchable questions or design corresponding investigations.

Alfred provided an example different from the others in that it is an umbrella project involving various different activities.

> *Alfred:* One example, which I usually work with in year 7, of how you can capture the students' own questions and help tie the different parts of science into a whole, is called the Long Journey. The idea is for students to work in groups equipping a spaceship for a fantastic journey that will last 2000 years. You are only allowed to use known technology, so it's not some kind of science fiction, and energy is not a problem either because they have solar energy. And they can never be more than 500 people on board and not have any contact with the Earth either. This will then lead to that you start thinking about the circulation of matter. And also questions like where does all the mass in a tree come from and how can a small seed become a large pine tree 50 years later? We work with this for approximately six or seven weeks, but not during every class period. In parallel, the science teaching is about air and water.

The project is done in cooperation with a social science teacher who treats topics such as justice and government. Some of the sub-activities are what Alfred calls "traditional laboratory tasks," and mentions an example of boiling and condensing water to study phase transitions. There is nothing to suggest that he has learning to do and learning about inquiry as explicit aims with any of the subtasks or the overarching project. This is an example of *Problem-Based Instruction* with the intended learning outcomes in terms of science subject matter (C).

These six examples seem to be quite typical for the tradition of science education in today's Swedish schools, as colleagues in teacher education, educational research and other teachers have confirmed when presented with them. Although the instructional approaches are varied, the knowledge aims are generally similar in that they focus on science subject matter. Ann-Catherin and Peter's examples were the only two out of all 18 that did not follow this trend. In these examples, the teachers had explicit learning goals that can be considered learning to do inquiry (A) and learning about inquiry (B).

All of the examples discussed during the interviews were classified according to the taxonomy (Table 2). The distinction between *Expository* and *Discovery* examples is difficult to assess and is based on how the teachers described these as a part of the teaching context. Out of the 18 examples, only four extended beyond one class period, such as the example with the toilet paper, which lasted for three classroom periods. It is particularly interesting to note that the notion of a research question was not a central or organising principle in any of the examples. This topic was explicitly addressed in all but two of the interviews, but none of the teachers said anything to suggest that this was an important concept in their teaching.

Table 2. Classification of all 18 examples

Type of instructional approach	Examples described	Number of examples, N=18
Expository	Christian: Showing the presence of starch	4
Discovery	Johan: Mixing alcohol and water	4
Problem-Based	Alfred: Designing a space ship	2
Guided Inquiry	Ann-Catherin: Exploring the secret box	6
Inquiry	Lina: Studying earth worms	1
Open Inquiry	Peter: Testing different toilet paper	1

Teachers' Own Descriptions of IOA: Pros and Cons

In general, the teachers valued IOA and the closely associated laboratory work for being fun and helping the students to better learn the science subject matter.

> *Johan:* I have discovered that the students learn a lot more when they work more laboratorially […] I believe that you use both cerebral hemispheres more if you do lab work. […] So it should stick better then. Also it's, of course, more fun to do lab work.

> *Lina:* When we studied electricity, they also had freer rein to connect [cables] any way they wanted, which they really thought was a lot of fun.

IOA was associated with a high degree of freedom, which was also something positive, as Lina suggests. Another aspect related to learning the subject matter is that instances of more open laboratory work are thought to stimulate the students to think more independently.

> *Ingrid:* In chemistry the laboratory tasks are quite structured, but in physics we have binders with more open laboratory tasks to let the students think more by themselves.

> *Alfred:* The best thing is, of course, when they come up and ask "can't we please check if it works like this?" on their own initiative. […] But that's like one of those ideal moments when you love being a teacher, that wow, now they have come up with an idea that they can actually test.

Alfred expresses an ideal in which students take the initiative to perform their own investigation out of curiosity. However, he also concludes that this is unusual, especially if it's also something that they can actually carry out. There is a suggestion here that all the teacher can do is wait and hope for the spontaneous curiosity of the students to awaken.

It was also expressed that IOA could be particularly well suited to students who experienced difficulties keeping up with the schoolwork in general.

> *Ann-Catherin*: An advantage with the less controlled experiments, I believe, is that the students who are somewhat tired of school would think it was more fun.

However, IOA was also problematic in many ways. Problems that the teachers raised included the students' lack of subject knowledge, the wide range in interests and levels of ambition, the students' worries and frustrations about conducting their own investigations, safety in that IOA was associated with spontaneous investigations, and general limitations in the schools' organisation. There were few suggestions that IOA was problematic because the teachers felt insecure about the meaning or nature of IOA.

> *Christian:* The fact that scientific investigations begin with a question, and so on, we don't talk about that much because they don't know what questions to ask. You must have something in your luggage before you start asking questions.

> *Johan:* When I was new as a teacher, I tried to have somewhat freer laboratory tasks, but I have discovered that you actually have to direct them as to what they should be looking for… The range is really wide in each class. […] It is a difficult act of balancing what level to choose.

An interesting discovery was what we came to call the students' "fear of observation" and "fear of hypothesis". This was expressed by Ann-Catherin, and somewhat more indirectly by Sonja. It refers to the students feeling uncomfortable imitating a research situation in which one aims to generate new knowledge, when the focus in school is simultaneously on learning a predetermined subject matter.

> *Ann-Catherin:* They are quite afraid of formulating a hypothesis or making a guess, which later proves to be wrong. Even though I […] point out all the time that it's important that they have thought about it and believe something about what result they could get before they get started, and that it doesn't matter if it doesn't turn out the way they initially expected.

> *Sonja:* If all that you are after is having laboratory tasks with degrees of freedom, I feel that it can give birth to a certain frustration.

The fear or insecurity many students seem to have in terms of formulating hypotheses and making their own observations may be connected with the fact that IOA is associated with discovery instruction. The students are encouraged to formulate hypotheses (as guesses what they believe will happen) while there simultaneously exists a right conclusion (Andrée, 2007) that they are expected to arrive at or “discover”. As the students know through the didactical contract (Brousseau, 1997) what type of knowledge is rewarded i.e. knowing and understanding the right conclusion, this artificial situation leads to conflict and stress.

Safety, particularly in chemistry, was emphasised as problematic in connection with IOA due to its association with spontaneity and freedom.

> *Christian:* Often, the laboratory tasks become a little bit more like recipes, so that as a teacher, I should be able to be more certain that nothing goes wrong. That’s why it’s difficult with this investigative way of working and being spontaneous. You could do that more often before when the rules were not as strict. Now, even though a question may be raised spontaneously during a class period, you can’t do a related laboratory task until you have made a risk assessment of it. On the other hand, you might be able to do it during the following class period, but by then the interest of the students has faded. You need to do it when it is current.

Christian was sceptical of IOA, and as we noted his teaching focused almost exclusively on traditional structured laboratory tasks. Ann-Catherin had similar concerns when it came to IOA. However, instead of scepticism, she expressed a certain amount of self-reproach for not being able to quite live up to the ideal that IOA seemed to represent for her.

> *Ann-Catherin:* All of this with an investigative way of working sounds very fancy, but it is not always that easy. For example, when you bring in dangerous items or talk about such concepts as an atom, which I can’t even actually show them. To be really satisfied with an investigative way of working demands a lot of time, so that I constantly have been able to think in advance about where it will lead. Otherwise, it’s very easy that I kill their interest at the next question. It is difficult for the students to ask their own questions when they are not familiar with a topic […] I would really like to get away from the structured experiments more, but it’s difficult […] I am probably bad at having a high degree of freedom except for the times when the students do an in-depth project.

In the quote above, the safety aspect and the problem that students are expected to start with their own questions are also reiterated. Furthermore, Ann-Catherin brings up the level of abstraction as a difficulty when she questions the possibilities of working with IOA on a topic such as the atom. This suggests that she associates IOA with hands-on activities.

On a more general level, limitations in the organisation of the school in terms of time, classrooms and materials were mentioned as problematic with IOA.

> *Catherine:* When we investigate things in class, new questions pop up all of the time, but it is difficult to get a good flow when the school is organized in such a strange way. Sometimes you would like to be able to do lab work for an entire afternoon and perhaps not just every four weeks when we have the time. In addition, you do not always have the same classroom, so you always have to put everything away afterward, which is another limitation.

In summary, it seems as if the problems that teachers associated with IOA are connected with the image of IOA as very free and based on the spontaneous curiosity and momentary impulses of the students.

Teachers’ Own Descriptions of IOA: Contrasts to Inquiry

The teachers described different forms of teaching related to IOA as a contrast between those that are associated with IOA and those that are not. This dichotomy appeared relatively uncomplicated, and the diverse and rich tradition of different teaching approaches that exist in schools does not seem to be accompanied by a specific professional language to talk about them. IOA was primarily associated with instances of laboratory work and hands-on activities. These were contrasted with "traditional teaching" or "didactical pedagogy". Two teachers expressed this by the following:

> *Peter:* I mix didactical pedagogy with letting the students do their own investigations […] The degree of freedom is high.

> *Alfred:* We also do some traditional laboratory tasks and traditional teaching that they can hopefully connect to this Long Journey.

The different expression that teachers used to describe forms of teaching was compiled into two categories (Table 3). There is reason to believe that this limited resolution in the ways of talking about different teaching approaches is also connected to the problems that teachers associated with IOA. The taxonomy presented here could be a useful tool for teachers to talk and think about different teaching approaches in relation to the multiple and complex aims and purposes of education.

Table 3. Expressions used by teachers to describe what is and what is not IOA

IOA	Not IOA
Do lab work	Teach in the usual way
Open tasks	Traditional teaching
Less structured experiments	Didactical pedagogy
Open laboratory tasks	Traditional laboratory tasks
Large degree of freedom	Structured laboratory tasks
High degree of freedom	Recipe laboratory tasks
Laboratory tasks with degrees of freedom	Predetermined laboratory tasks
Independent investigations	Structured experiments
Students get to discover on their own	Filling students with facts
Problem-based	Reading, writing, calculating
Hypothesis-laboratory-task	

Discussion

In this study, we set out to explore what secondary science teachers describe as their own examples of inquiry-oriented teaching approaches. The examples that teachers brought to the interviews and that were brought up during them can be considered a "core sample" (Cobern & Loving, 2000, p. 4) of an existing tradition of practical work in science education in Sweden today. Examples ranged from expository cookbook style laboratory tasks to open inquiry in which students formulate questions and design investigations. As instructional approaches, most examples shared some element of "hands-on" activities as well as a focus on teaching students science subject matter. However, some examples did not have a clear connection to "hands-on" activities, thus indicating that teachers may not always equate inquiry with "hands-on", and that the conceptual borders of teaching approaches are fuzzy. Examples of instructional activities of all degrees of freedom were found, although lower degrees of freedom dominated. It was unusual for teaching activities to stretch beyond one class period, and only four out of eighteen examples were allocated more time. The diversity of the existing tradition of instructional activities does not seem to be accompanied by a correspondingly diverse language for teachers to talk about and describe the different approaches they use.

Practical work in general and IOA were valued by teachers for reasons such as it being fun and for promoting learning and remembering content. These positive aspects related to the perceived pedagogical value of hands-on activities and the fact that IOA was associated with a high degree of freedom in students' work. In addition, this freedom was valued for promoting students' independent thinking skills. However, as we focused more closely on aspects particularly related to inquiry during the interviews, some teachers expressed doubts and problems. For them, IOA seemed to represent a lofty ideal, sometimes worth striving for, but difficult or unrealistic to attain. The basic conflict that the teachers seemed to express or hint at in different ways was the problem of using a method of teaching characterised by them as free, open and spontaneous, to teach young learners a fixed set of scientific theories, laws and facts. In other words, the problematic nature of IOA seems to be found in the friction between what teachers associated with IOA and the constraints they perceived on their teaching situation.

IOA was associated with hands-on activities, discovery instruction, freedom, students' independence and spontaneity. The constraints were the subject content matter as the dominant knowledge goal, the students' diverse background knowledge, interests and abilities of the students and the general constraints of the school, such as time, classrooms and materials. Combined in different ways, the conceptualisation of IOA and the constraints led to the problems of safety, frustration and uncertainty of reaching the intended knowledge goals. Given that IOA was associated with hands-on activities and using students' spontaneous interests and questions to guide investigations, safety was considered an issue, especially in chemistry. This seems to be connected with a view of hands-on activities as rather fast and short in duration. In addition, because IOA was associated with discovery learning, freedom, students' independent work and the emphasis on learning science subject matter (C), the result could be different forms of frustration in the classroom. In particular, we noted the comments about students' fear or uneasiness when it came to formulating hypotheses and drawing conclusions based on their own observations. This was further complicated due to the fact that all of the teachers used the notion of a "hypothesis" as the equivalent of a prediction or guess, rather than a tentative explanation, reducing the act of formulating a hypothesis to guessing the correct conclusion. This issue was explored in more depth in another article based on the same study (Gyllenpalm, Wickman, & Holmgren, 2009).

With this study, we also wanted to compare how the teachers' own examples related to conceptualisations of inquiry in the science education literature. Inquiry has been conceptualised in science education both as an instructional approach and a learning outcome. We chose to focus on two learning goals specifically associated with inquiry in the literature: learning to do inquiry and learning about inquiry (Bybee, 2000). These knowledge goals that were specifically associated with inquiry were found to be almost completely absent in the teachers' descriptions of their own teaching, in line with what other researchers have found (Högström, 2009; Högström et al., 2005; Lederman, 1999; Windschitl, 2004). Some of the examples exhibited features of inquiry as a teaching method in that they attempted to mimic authentic scientific research (e.g. investigating toilet paper). However, the central notion of structuring investigations around a question did not seem to be important in the existing tradition. Thus, it can be concluded that although there are teaching practices in the existing tradition that exhibit elements of inquiry as an instructional approach, they are not matched with learning goals specific to inquiry.

The findings in this study have implications for teachers who want to reflect on the nature of practical work as a part of their teaching as well as for the development and use of curriculum materials based on ideas about inquiry. This study suggests that inquiry-oriented approaches will remain problematic unless learning about scientific inquiry and learning to do inquiry are give more emphasis as explicit knowledge goals. The division between learning science subject matter and learning about inquiry is analytical, and we do not believe that one can learn about inquiry without also acquiring a certain grasp of the subject matter. It is obvious that the process of teaching science is not linear, and the emphasis between subject matter and learning about inquiry will have to shift in a cyclical manner. Although learning about inquiry is not the only objective with science education, we want to highlight the importance of matching the emphasis of distinct knowledge goals with distinct methods of teaching. This involves considering *methods of inquiry* (such as control of variables, formulating researchable questions, formulating hypotheses and using random sampling) as part of the subject matter that students learn as distinct from other more well-known domains of subject matter (such as the laws of mechanics), and to match the learning goals with *methods of teaching* in a reflective way.

If the primary focus is on teaching students science subject matter (C), then the instructional styles in which the answers are given will seem more relevant. In *Expository Instruction* and *Problem-Based Instruction,* the science subject matter is always close in view. The other approaches are problematic from this point of view because it is uncertain whether the students will reach the anticipated conclusions, especially in a given time frame. Given that IOA was associated with discovery instruction, freedom and students working independently, reaching the learning goals in terms of subject matter became problematic. Furthermore, as IOA was also associated with hands-on activities, the subject matter that is considered more theoretical and abstract appears even more problematic. *Inquiry* and *Discovery* instructions may then only be favoured based on the belief that if done well, it will help the students to remember the content better and perhaps make science education more enjoyable. Thus, from the point of view of teaching the correct explanation, these styles of instruction have pedagogical value for the teachers only in a disconnected way from their primary knowledge goals. In fact, research is ambivalent regarding the relative effectiveness of inquiry-oriented teaching approaches to teach science subject matter (Lederman, Lederman, Wickman, & Lager-Nyqvist, 2008). These problems with inquiry instruction may possibly increase as students get older and begin to realise the trade-off between investing time and energy in doing inquiry versus focusing on learning the correct explanation, which is more important in assessments where learning the correct explanations is usually given more emphasis.

Previous research has identified some of the same themes presented in this study, such as the dilemmas teachers express in relation to inquiry (Anderson, 2007), and that inquiry is an ambiguous term in science education (DeBoer, 1991). The fact that practical work with higher degrees of freedom and learning about inquiry as a goal are unusual has also been described (Hult, 2000; Högström, 2009; Högström et al., 2005; Löfdahl, 1987). The new contribution of this paper is that it provides a first-hand description of teachers' own examples of IOA and how they conceptualise inquiry, and that these descriptions are related to the ongoing discussion about inquiry in science education research and policy. We also propose that some of the problems and dilemmas that teachers describe with IOA can be resolved by clearly distinguishing between *methods of teaching* (e.g. the instructional approaches described in Table 1) and *methods of inquiry* (e.g. control of variables), where the latter are a goal of instruction and the former a strategy for instruction. The taxonomy of instructional approaches presented here is also new and can be used to consider what approach would be more useful at certain points in the progression of a teaching unit.

The development and implementation of curriculum materials and curriculum reforms needs to take into account the existing tradition and school culture. Discussions about education are generally more productive if one begins with the intended learning outcomes, the “what-question” and then moves on to the “how-question” of teaching methods. This is especially precarious for the notion of inquiry in science education, as there is a high risk of misunderstanding when talking about *methods of inquiry* as a learning outcome and *methods of teaching* through inquiry as a pedagogical strategy. What this study suggests is that teachers have a strong tradition of practical work that they associate with IOA in various ways. Although the notion of IOA is not problematic for many teachers, working with IOA may be. If teachers choose not to work with IOA, their reasons for doing so may be different from what has been assumed in curriculum reforms, i.e. that teachers need professional development in inquiry teaching. The problems teachers raised in this study concerned aspects such as time, safety and students’ interest, rather than a lack of understanding IOA or a lack of materials. The fact that the teachers’ examples in some ways resembled inquiry, as conceptualised in the science education literature, but also lacked essential elements, and the ambiguities in terminology to describe instructional approaches are issues that needs to be addressed. Otherwise, new curricular materials and reforms may be absorbed into the existing tradition and transformed into more of what already exists.

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