Doctoral Thesis from the Department of Mathematics and Science Education

Jakob Gyllenpalm
Teachers’ Language of Inquiry
The Conflation Between Methods of Teaching and Scientific Inquiry in Science Education

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Abstract

The objective of this thesis is to describe and analyse customs of science teaching in secondary schools and teacher education programmes in Sweden in relation to the notion of “inquiry” in science education. The main focus is on customs of language use and the educational goal of learning about scientific inquiry as distinct from the related goals of learning to do inquiry and learning canonical science content. There is also an exploration and description of different teaching approaches associated with “inquiry”. Previous research has noted that a key issue for reaching the goal of learning about scientific inquiry is the extent to which teachers are able to guide students to explicitly reflect upon this topic. A prerequisite is that teachers give students access to relevant categories of language for explicit reflection on the characteristics of scientific inquiry. Because of the situated nature of language use and learning, this also raises the need to address topics of context, culture and customs in science education. This thesis addresses the questions of how existing customs of teaching science are related to the goal of learning about scientific inquiry, how inquiry-related terminology is used in this context, and how relevant distinctions can be made to aid explicit reflection on these issues. Data has been collected in two studies and analysed and presented in four papers. Study 1 is based on interviews with twelve secondary school science teachers, and Study 2 is based on focus group interviews with 32 pre-service teacher students. The results include a description of the existing customs of inquiry-oriented instructional approaches in Swedish secondary schools. They show that these are often not connected with an explicit focus on teaching about the characteristics of scientific inquiry. Inquiry-related terminology is analysed with a focus on the role and use of the terms “hypothesis” and “experiment”. Based on a theoretical framework of sociocultural and pragmatist views on language and learning, it is shown how the use of these terms, both in secondary schools and teacher education, tend to conflate the two categories methods of teaching and methods of scientific inquiry. Some problematic consequences for reaching the goal of learning about scientific inquiry are discussed, as well as possible origins of the problems and how the results from this thesis can be useful in overcoming these.
Keywords: inquiry, secondary school, teacher education, laboratory work, hypothesis, experiment, language, sociocultural, pragmatism, customs, cultural institutions, pivot term, nature of science, focus groups.
List of Papers

This thesis is comprised of a summary of four papers, which are referred to by their Roman numerals:


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Preface

The initial impetus for this thesis was a curricular development project based on ideas about inquiry-based science education (IBSE) called Naturvetenskap och Teknik för Alla (NTA). NTA was initiated by the Swedish Royal Academy of Science in 1996 (www.nta.kva.se), and was modelled after US curricular material called Science and Technology for Children (STC). Although the idea was initially to study the implementation and evolution of the NTA material, my research quickly evolved to more general questions concerning traditions of inquiry-oriented teaching, and in particular, in relation to the role of language in science learning. The findings presented here are nevertheless relevant for NTA, STC and other curriculum projects associated with the notion of inquiry in science education. However, this thesis also goes further in being a critical analysis of certain traditions of science education directly relevant for both teachers and teacher educators.

It may seem strange to ground a thesis in science education in Sweden by drawing on US and UK sources to such a large extent. Even to write the thesis in English may require some commentary. One reason is that science education in Sweden has been influenced by much of the same trends as those that have permeated the United States and UK. One example is the NTA project. In addition, given that many of these influences come from US and UK sources, and given the amount of scholarship produced in English on this subject, it was natural to use this body of research as a starting point for the present thesis. In doing so, it was also natural to write in English to contribute to and receive feedback from this larger community of scholars interested in the same or similar topics.

A major part of this thesis is a critical analysis of habits of language use, with a focus on the use of certain words. A possible misunderstanding I want to prevent is that I am policing language by saying what certain words actually mean, as if there was only one correct way of using them. This is not my intention. A perfectly rigid language in which every word has a definite and exact meaning is not possible. By nailing down some words to “stand fast” as Wittgenstein puts it, one must simultaneously let other meanings remain dynamic, floating, and not too strictly defined; it is simply the nature of language. This thesis points out how certain words tend to be used in certain contexts and what this means in relation to certain purposes. In this sense, it is similar to describing a set of geometrical relationships. Hence, the real issue that must be addressed, and one that is not as simple as geometry, is the
question of what goals, purposes and values one should aim to achieve in education. Hopefully this thesis can provide some points of reference for orientation in such a dialogue.
Introduction

The topic of this thesis is the role of language in learning and teaching science with a special focus on ideas about “inquiry”. Inquiry has been a buzzword in science education for a long time. Already a century ago, John Dewey wrote extensively about the idea of inquiry as an organizing principle in education and particularly in science education (Dewey, 1910, 1916). Today, many policy documents, curriculum materials and programmes worldwide are based on the idea that inquiry should be a guiding principle in science education (I.A.P., 2005; National Research Council (U.S.), 2000; Rocard, 2007). However, the notion of inquiry in science education has been and continues to be accompanied by widespread confusion about its meaning (Anderson, 2007; DeBoer, 1991). In part, the reason may be, as supported by this thesis, the fact that inquiry is used to refer both to a content students should learn, and to a pedagogical strategy for teaching science (Bybee, 2000). As a pedagogical strategy, inquiry assumes many shapes and forms. However, it is generally associated with the idea that students should learn science by, in some sense, imitating scientists in the way they conduct research. Although research remains ambivalent as to the relative effectiveness of inquiry as a pedagogical strategy for teaching science (Lederman, Lederman, Wickman, & Lager-Nyqvist, 2008), many educators and educational researchers believe that it can nevertheless serve many valuable purposes (O'Neill & Polman, 2004).

As a content to learn, the educational goals associated with the idea of “inquiry” in science education must be understood in relation to how the science curriculum is conceptualised as a whole. A science curriculum is by necessity a selection of the vast set of knowledge and practices that may fall under the topic of “science”, and it is far from obvious how this selection should be made. In the history of curriculum development, this selection has been made in different ways and with different emphases (DeBoer, 1991). The current (soon to be replaced) science curriculum for secondary school in Sweden is grouped into three categories of topics: concerning nature and man, concerning scientific activity, and concerning use of knowledge (www.skolverket.se). Another way of doing this is exemplified by Roberts (1982), who analysed science textbooks and devised a typology of seven different curriculum emphases to describe their content. The point is that this selection and grouping can be, and has been, made in different ways. A division common in discussions of “inquiry” is to use the following three cate-
categories: learning to do scientific inquiry, learning about scientific inquiry, and learning canonical science content (Bybee, 2000; Hodson, 1996; Lederman, 2004).

Learning to do inquiry includes a set of skills that students need to master to “do science”, but it also extends beyond mere process skills. It also means combining these processes with scientific knowledge, reasoning and critical thinking to develop a scientific account of some aspect of nature (Lederman, 2004). Learning about inquiry includes knowing about how scientific knowledge is developed. Knowledge about inquiry would, for example, include knowing that scientific investigations are derived from a question or hypothesis based on previous knowledge, and that answering scientific questions involves empirical data. These goals signify a focus on understanding the knowledge-building enterprise of scientific research. It is connected to an emphasis on the need for students to develop an understanding of science beyond scientific concepts and facts, an understanding that has been argued to be fundamental to scientific literacy (Roberts, 2007). Learning canonical science content refers to learning the conceptual products of science: the textbook explanations, models and concepts. This learning outcome is generic and not connected to “inquiry” in any specific way, and includes all categories of curricular emphases or goals not explicitly associated with inquiry, including for example learning about socioscientific issues, and the “use” or applications of scientific knowledge.

The educational goal of learning about scientific inquiry has led many to suggest that students need experiences of doing scientific inquiry in order to learn about it. However, a problem identified by previous research is that learners do not necessarily develop an understanding of scientific inquiry as a result of just doing inquiry-oriented activities (Abd-El-Khalick & Lederman, 2000; Trumbull, Bonney, & Grudens-Schuck, 2005). Similarly, learners do not generally develop an understanding of the nature of scientific knowledge as a result of engaging in scientific inquiry alone, regardless of whether the learners are school students, teachers, or scientists (Schwartz, Lederman, & Crawford, 2004). For learners to develop an understanding of these, they also need, in addition to the proper experiences, guided attention to and explicit reflection on such topics (Abd-El-Khalick & Lederman, 2000). Learning to explicitly reflect upon the nature of scientific inquiry can be described as being introduced to a new discourse and it is primarily teachers who direct how learners meet these new discourses (Bartholomew, Osborne, & Ratcliffe, 2004; Kelly, 2007; Leach & Scott, 2003). To do this, it may not always be necessary to actually do inquiry in order to learn about it, as Schwab (1962) has argued convincingly (although he certainly placed a great value on providing students with real experience of scientific inquiry). So, in addition to providing students with inquiry experiences, teachers also need to have the necessary tools and abilities to reflect upon the nature of scientific inquiry on a conceptual level. A prerequisite for this is that teach-
ers have a functional language for discussing scientific inquiry as a conceptual topic. This can include reflection on what they have done in inquiry projects, what they are doing while engaged in inquiry, and what others have done and are doing in scientific research. These considerations suggest that issues of language and learning may hold a key to understand the problems of teaching about the nature of scientific inquiry.

The increased interest in sociocultural perspectives on teaching and learning science has meant an increased focus on issues of language in science instruction. In their review of research on language in science education, Yore, Bisanz and Hand (2003) conclude that language issues tend to be neglected in science classrooms and that the quantity and quality of oral interactions is generally low. They suggest that any type of hands-on or inquiry-oriented activities need to be accompanied by an active engagement with language. An example of this is given by Crawford, Chen and Kelly (1997), who emphasise the need for explicit instruction on elements such as style, purpose, audience and the role of language in scientific knowledge building. A similar argument is made by Sutton (1992), based on the connection between understanding the development of scientific knowledge from a historical perspective and the historical development of scientific discourses. Likewise, Carlsen (2007) has suggested that there is a need to address language as an educational outcome, and not just a means in science education. Knowledge, both in terms of learning to do and learning about inquiry, involves acquiring a language in order to talk and communicate about investigations and their results. These findings further support the need to examine the role of making language use explicit for reflection in science education in general, and thus also for learning about scientific inquiry in particular. It also suggests that many dimensions such as cultural and historical aspects must enter into such an account. Language is not an isolated phenomenon, but must be understood as highly contextual and reciprocally connected to cultures and traditions (Rogoff, 1990; Säljö, 2005; Wittgenstein, 1968; Östman, 1998). Therefore, in order to understand issues of language, one must simultaneously study the activities of which it forms a part. Conversely, an understanding of human activities and actions often requires consideration of the language use it involves and through which it is constituted.

As an institutionalised practice, science education has developed over a long period of time and established its own characteristic set of customs. Although such customs are necessary for growth and continuity, they also have a tendency to become disentangled from their original aims and purposes. When this happens, actions that were once purposive may be transformed into unreflective habits, and old customs may contradict or obstruct new aims and purposes. One reason for this is that customs and traditions are often largely unexamined by the members of a culture or institution (Dewey, 1930). In addition, language can, to a large extent, be understood as consisting of customs and habits that we use without thinking about them. Research
has suggested that in order for the development of new curricular materials (e.g. NTA and STC) and reform efforts (e.g. the new Swedish curriculum) to contribute positively, teachers’ voices and existing school cultures must be taken into account (Keys & Bryan, 2001; Trumbull et al., 2005). Otherwise, development is likely to be obstructed by participants acting on different, unarticulated and unchallenged assumptions about key issues (Fredrichsen, Munford, & Orgill, 2006; Trumbull et al., 2005). Avoiding this requires active reflection on the existing customs, and a prerequisite is that the traditions are first made explicit. To do this, Keyes and Bryan (2001) identified the need to develop a mutual language of overlapping cultures for the sake of both student-teacher interactions, but equally important, researcher-teacher interactions. This suggests a need to examine the relationships between cultural institutions relevant to science education and customs of language use within these, in relation to the problem of teaching students about scientific inquiry.

An important subculture of science education at large is teacher education, which forms a link between authentic scientific inquiry as research and the school subject of science. Windschitl, Thompson and Braaten (2008) conclude that it is important to know how teacher students and teachers conceptualise scientific inquiry in order to create successful college and in-service courses. Furthermore, teacher students need help to translate their experiences of scientific inquiry into manageable classroom practices (Britner & Finson, 2005). This “translation” requires explicit reflection on, and thus a need to make relevant distinctions between, the significant differences and similarities between authentic scientific inquiry as research on one hand, and inquiry as a pedagogical strategy in the school subject of science on the other.

**Objective and Guiding Research Questions**

The objective of this thesis is to describe and analyse aspects of the existing customs of science teaching in secondary schools and teacher education programmes in Sweden, with a focus on the educational goal of learning about scientific inquiry. The main focus is the customs of language use relevant for understanding scientific inquiry. The purpose is to make these customs explicit to reflect upon and contribute to an understanding of how they provide affordances and constraints for the achievement of this goal. A better understanding of these issues is relevant for teacher educators and developers of curriculum materials, and it can also indicate distinctions that are both inspiring and useful for teachers directly. Despite the diversity and situatedness of research concerning inquiry in science education internationally, Abd-El-Khalick et al. (2004) found that many themes and issues extend across national boundaries—supporting the international relevance of this
thesis. Also, since many studies on inquiry in science education involve elementary and middle-school teachers and students, there is a need for more studies on inquiry practices in secondary schools and teacher education (Keys & Bryan, 2001). The guiding research questions of this thesis are:

1. How are existing traditions and customs of teaching science related to the educational goal of learning about scientific inquiry?
2. How is inquiry-related terminology used in science education settings such as schools and teacher education programmes?
3. How can relevant distinctions concerning customs and language use be made explicit for reflection?

As a qualitative study, the aim is to provide a basis for informed deliberation and decision-making in science education. This includes the moment-to-moment work by teachers in their classrooms, the planning of large-scale curriculum reform, as well as the development of various educational materials such as textbooks. This thesis presents insights that can be relevant for better decision-making at all age levels of science education, from primary school to the university level. It was not initially my intention to include such a broad scope; rather, it is a consequence of the particular aspects of science subject matter on which this thesis has come to focus. The concern is the relationship between authentic scientific research on the one hand, and science as a school subject on the other, a relationship that needs to be considered in various ways at all levels of education. This thesis provides no exact explanations and no certain predictions. What it does provide, hopefully, is a new way of looking at some old issues that may inspire those concerned to make more informed decisions regarding science education.
Theoretical Framework

A Sociocultural and Pragmatist Perspective

The development of sociocultural theory has involved a widening of the research scope on learning, from being focused primarily on individuals’ cognition, to an emphasis on the role of communication and its historical, situational and cultural characteristics and conditions to conceptualise learning (Barab & Plucker, 2002; Hamza & Wickman, 2007; Lemke, 2001; Säljö, 2000; Wertsch, Del Rio, & Alvarez, 1995). In this thesis, this has primarily meant focusing on how categories of language, as cultural artefacts, mediate action and thus create affordances and constraints for learning in science education (Wertsch, 1998). It also provides a rational for describing and analysing the characteristics of science teaching as a cultural practice. The philosophical orientation of pragmatism, as developed for research in education, has provided a way to handle questions of language and meaning. This means that instead of considering language as an outer expression or representation of an inner mental state, as is usually the case in cognitive perspectives, the meaning of words or any utterances are to be found in their use and consequences (James, 1907, 1995; Wickman, 2006; Wickman & Östman, 2002). The combination of these two perspectives has guided this thesis from the formulation of research questions to the design of the studies, as well as the analyses and interpretations of the results.

Mediated Action and Cultural Institutions

The task of sociocultural theory is to explicate the relationship between social, historical and cultural contexts on the one hand, and individual action on the other (Wertsch, 1998). In this thesis, the particular cultural contexts are those of school, university education and scientific research, which I will refer to as cultural institutions (Rogoff, 1990; Säljö, 2005). Following Wertsch, the unit of analysis for explicating this relationship is mediated action. Mediated action refers to an agent acting by means of, or mediated by, cultural artefacts, including both physical tools (e.g. a hammer) and intellectual tools (e.g. numbers, words, categories of language) (Wertsch, 1998).
Tools such as these are cultural artefacts, as they have developed over time within a social and cultural context and have an existence both before and after a particular agent makes use of them (Säljö, 2000). Furthermore, they have a history and their use must be understood in a historical context, or as part of a developmental path (Wertsch, 1998). The historical trajectories of cultures are not generally explained by regular laws, as might be the case in explaining aspects of nature, but rather understood by examination of the situational particulars, contingencies, consequences and human purposes (von Wright, 1971). Mediated action must be considered in the same fashion.

Cultural institutions are relatively stable systems of human relations, communicative patterns, physical artefacts, activities, routines and other types of social arrangements on various levels of complexity that stabilise social interaction and which humans learn to relate to and act within (Säljö, 2005). They include both bureaucratic and hardened dimensions as well as more informal systems of practice (Rogoff, 1990). Hence, institutions are systems of established and embedded social rules that structure social interactions, although the rules are not always explicit and compelling in a definite way (Hodgson, 2006). The modifier ‘cultural’ refer to the fact that these institutions also embody cultural values and purposes (Rogoff, 1990), and have been shaped by their particular historical and contingent developmental path (Wertsch, 1998). The conceptual borders of cultural institutions are abstract and difficult to define. However, two cultural institutions such as school science and scientific research can be more clearly distinguished based on an analysis of purpose (Cherryholmes, 1999). The main objective of scientific research is to develop new knowledge and new methods, whereas the main objective of science education is to introduce learners to an established body of knowledge and methods (Metz, 2004). This emphasises that although these cultures may overlap, they are analytically distinguishable.

**Language, Habits and Culture**

Language can be conceptualised as the most ubiquitous cultural artefact, and thus also mediational means (Säljö, 2005). We communicate, act and think by using a language that is the product of a long historical and cultural evolution, which in turn shapes the way we communicate, act and think. Also, our uses of language, including particular distinctions and divisions, is to a large extent habitual (Wickman, 2006). Habits here refer to predispositions and tendencies for certain kinds of actions in certain situations (Dewey, 1930), and not strictly repetitive behaviour in a biological sense (Cohen, 2007). Cultural institutions and the habits of individuals constitute each other reciprocally. Institutions are upheld by the habits of individuals, simulta-
neously as institutions and the mediational means they provide, shape individuals’ habits (Dewey, 1930; Hodgson, 2007; Maréchal, 2010). These collectively shared habits, which characterise cultural institutions, are here called customs (Dewey, 1930; Cohen, 2007). The customs of science education as an institutionalised practice or culture can thus be studied by making explicit the particular uses of language used within it. Being socially transmitted, habits require the attention and will of the agent while learning them, but once established, they tend to function without explicit conscious reflection. Nevertheless, habits can be made the object of explicit deliberation, which is the first step in changing them, and the transformation of habits for coping with new situations can be conceptualised as learning (Rorty, 1979; Wickman, 2006).

Although it is common in sociocultural theory to refer to language as an artefact, it must be remembered that language has not been invented or designed as in the example of the hammer. Wittgenstein’s investigations into the nature of language demonstrate that language and human activities are inseparable and, to a large extent, taken for granted in an unreflective way, captured somewhat in his suggestive metaphor of language as a “form of life” (Wittgenstein, 1968). This habitual and unexamined nature of language use and learning, and its place in social life, was described succinctly by Dewey:

Fond parents and relatives frequently pick up a few of the child’s spontaneous modes of speech and for a time at least they are portions of the speech of the group. But the ratio which such words bear to the total vocabulary in use gives a fair measure of the part played by purely individual habits in forming customs in comparison with the part played by custom in forming individual habits. (Dewey, 1930, p.59)

The argument by Dewey that follows is that habits both form the basis of thinking and that intelligent deliberation simultaneously involves the examination and readjustment of these habits in relation to continually emerging purposes.

As a perspective on learning, sociocultural theory involves an emphasis on that learning is not a singular phenomenon, as previous research programmes with a more cognitive approach have tended to assume. Instead of conceptualising learning as a “phenomenon”, which is straightforward to delineate in the abstract, learning needs to be understood as a mode of human action in a particular context and situation (Säljö, 2005; Wertsch, 1998). In the case of school, this also includes its relation to a specific content. As a mode of action, learning needs to be described in terms of what it means for humans to become competent actors, and that always includes reference to a culturally, historically situated activity that involves purpose. This means competent action with and through, i.e. mediated by, cultural artefacts, and
in particular action mediated by language. This is especially important for understanding learning in institutionalised practices such as school science, in which the objective is, to a large extent, to introduce a new generation to existing conceptual systems and methods for doing things, systems that have evolved as particular discourses for understanding the natural world for hundreds of years.

Pivot Terms

From a pragmatist perspective on language, words do not have an essential or universal meaning but must be understood as part of an activity, context, or what Wittgenstein called a ‘language-game’ (Wickman, 2006). The meaning of a word or concept lies in its consequences (James, 1907, 1995; Wickman, 2004). Hence, an isolated word is, in a sense, an imaginary abstraction and has meaning only when used in a context, which means that it has consequences for action (Wittgenstein, 1968). In this regard, it is important to point out that speaking is also a form of action. To understand a word is at the same time to know how to play the language game it is a part of. As mentioned, language can, to a large extent, be understood as functioning through habits and customs. In language games, the use, and thus meaning, of words is usually not questioned, but is typically understood as part of a practice as a whole (Hardwick, 1971). The fact that most utterances ‘stand fast’, i.e. are not questioned by the individuals participating in an activity, is a necessary condition for communication (Wickman & Östman, 2002; Wittgenstein, 1968). This means that to learn a language game does not simply involve knowing the use of certain words but also acquiring habits of using these words as part of an activity (Wickman, 2004). In order to reflect on the customs (i.e. shared habits) of the major cultural institution relevant to science teacher education, it is therefore relevant to study and make explicit the particular uses of language associated with them (Östman, 1998).

I have defined a pivot term as a single word or term that can be used to highlight how two or more different cultural institutions and their associated language games overlap or intersect. It can metaphorically be described as a term on which one can balance two such systems—a common point around which they can be said to revolve. A pivot term thus relates to some central aspect of two or more activities, or language games, with distinctively different purposes, resulting in the word having radically different meanings and connotations in these activities. If the customs of using a particular term differs significantly between two cultural institutions, it may be described as a pivot term. The same pivot term may thus mediate quite different actions in different activities. Pivot terms are special compared to other words, only because they can be positioned to provide a point of leverage for analytically separating two or more activities. This is not an essential or universal quality.
of a certain class of words, but a description of a role or function that a term may play when comparing its customary use in relation to the different purposes of different cultural institutions. Hence, analysing the use of potential pivot terms is a way to operationalise how specific words can play a central role in mediating action.

Experiments and Hypotheses in Authentic Scientific Research

In activities associated with distinct purposes, technical language use evolves in which certain words, which may be commonly used with vague or ambiguous meanings, are used in more definite ways. This thesis provides an in-depth analysis of the customs and practices within the cultures of school science and teacher education. As a normative reference I use the customs and practices within the culture of authentic scientific research, which are part of the educational goal of learning about scientific inquiry. Because the potential pivot terms that I have come to focus on in this thesis are “experiment” and “hypothesis”, there is need to review the function and use of these terms in authentic scientific research.

The word “experiment” in science is often short for “controlled experiment” much in the same way as “science” is frequently used for “natural science”. The controlled experiment is a particular methodology for studying causal relationships as part of scientific research. The essence of an experiment involves actively making a change in some system or group of systems and studying the effects of this change (Bock & Scheibe, 2001; Wilson, 1990). The objective is to test hypothesised links of causation or functional relationships, i.e. tentative explanations.

An experiment usually consists in making an event occur under known conditions where as many extraneous influences as possible are eliminated and close observation is possible so that relationships between phenomena can be revealed. The ‘controlled experiment’ is one of the most important concepts in biological experimentation. In this there are two or more similar groups (identical except for the inherent variability of all biological material); one, the ‘control’ group, is held as a standard for comparison, while the other, the ‘test’ group, is subjected to some procedure whose effect one wishes to determine. (Beveridge, 1961, p.13)

The terminology may vary slightly between different research fields, and the descriptor “controlled” may be taken for granted. The variation in terminology can also specify in more detail the type of control used in an experiment, as in “quasi experiment” and “double blind experiment”. This applies both to the natural sciences and social sciences (Neuman, 2005).
The basic idea of the controlled experiment has often been identified with “the scientific method” (TSM) (Lederman, 2004). In contrast, scholars in science studies agree that there is no single scientific method (Rudolph, 2002; Windschitl et al., 2008). The widespread custom in science education of teaching TSM as an algorithm of a few steps has been recognised as seriously misrepresenting science to learners (Rudolph, 2002; Windschitl, 2004). Nevertheless, the notion of an experiment in science is fundamental and has been of such monumental importance that it is not surprising that it has sometimes been equated with science itself.

Science as we know it today may be said to date from the introduction of the experimental method during the Renaissance. Nevertheless, important as experimentation is in most branches of science, it is not appropriate to all types of research. It is not used, for instance, in descriptive biology, observational ecology or in most forms of clinical research in medicine. (Beveridge, 1961, p.13)

Although Beveridge’s words are half a century old, they are still valid (Lederman, 2004; Wilson, 1990).

An experiment is often motivated by either an observed or hypothesised correlation. In science, the word “hypothesis” refers to a tentative explanation related to some observed phenomena (Chalmers, 1999). Often, it is a proposition about a correlation or causal mechanism. What follows are three examples of hypotheses from recent scientific research. All examples are taken from articles published in Nature in 2000 (Hansson, 2006).

1. Neurotransmitter receptors of type D5 differ from those of type D1 in having special functional interactions with $GABG_4$ receptors.
2. Certain gravel depositions in Hawaiian coastal slopes were created in a single event by giant tsunamis.
3. Super conductivity will arise in $C_{60}$ at high temperatures if it is hole-doped.

These hypotheses all have in common that they state tentative explanations in different ways, with reference to causal or functional relationships of natural phenomena. Example one proposes a “functional interaction”, example two proposes how a geological feature was “created” (i.e. caused) and example three proposes “hole-doping” as a factor that might cause the phenomenon of “super conductivity” under certain conditions. Furthermore, all of these hypotheses contain theoretical concepts (e.g. superconductivity, neurotransmitter, gravel deposit) that have meaning only in relation to a more comprehensive theory and research programme of some kind. Example three may be superficially mistaken for a prediction. If one only considers the grammatical form, this may be true, in a sense; however, the key here is
the second part, “if it is hole-doped”. This refers to a cause or explanation of the predicted superconductivity in this particular case. For this explanation to make sense, the hypothesis must be connected to a more comprehensive model relating the particulars of $\mathcal{C}_60$ within the even more comprehensive theory of solid state physics. This implies that a hypothesis cannot stand alone, and that the theory or research objective to which it is related is needed to separate a scientific hypothesis from a groundless guess about an outcome or arbitrary fortune-telling. It can be questioned whether hypotheses play an important role in all forms of scientific research (Hansson, 2006). However, it is definitely widely used in science studies in the way described here, which is the field of scholarship in which the nature of scientific inquiry is systematically studied and described.

Lederman (2004) describes scientific inquiry as “the systematic approaches used by scientists in an effort to answer their question of interest” (p. 309) (Note the word “approaches” to emphasise that there is no single scientific method or algorithm). To exemplify this, Lederman distinguishes between descriptive, correlational, and experimental research. He describes experimental research as involving “planned intervention and manipulation of variables … in an attempt to derive causal relationships” (p. 309). It is an important learning outcome, in terms of learning about science, to understand the difference between a correlational and a causal or functional relationship. One reason is for students to make sense of much of the research reported in the media, e.g. about climate change and health issues (Norris & Phillips, 2003). Another reason is to understand that the methodology of the controlled experiments is important in science, but that it is not equivalent to TSM; there is no one scientific method, and different methods are used for different types of questions, resulting in qualitatively different kinds of knowledge.
Methods

The methods of inquiry used in this thesis can be divided into two categories: methods of data collection and analytical methods. The methods of data collection can be further sub-divided into two kinds. In Study 1 I used the method of individual semi-structured interviews, and Study 2 involved focus group interviews.

Study 1: Individual Semi-structured Interviews

The objective of Study 1 was to explore and describe qualitatively different inquiry-oriented teaching approaches, teachers’ descriptions of these, and the use of inquiry-related terminology in this context, in Swedish secondary schools. In order to obtain information about a broad range of examples from the existing school customs and simultaneously have the opportunity to explore these in some depth, qualitative semi-structured interviews were chosen as the method of data collection (Neuman, 2005).

Participants

Given that Study 1 was both explorative and qualitative, diversity was considered more important than a random selection of participants (Neuman, 2005). To achieve a strategic sample, I used three criteria to guide selection: years of experience as a teacher, an equal number of men and women, and teachers working at schools in a variety of neighbourhoods. Twelve secondary science teachers agreed to participate, with teaching experiences ranging between 5 and 30 years. The teachers also had a variety of different experiences with in-service training regarding inquiry.

Interview procedure

The participants were asked to bring examples from their own teaching that they considered to represent an inquiry-oriented approach (IOA) (ett undersökande arbetssätt in Swedish) to science teaching in some way (e.g. instructions for lab work or other materials used in their teaching). IOA were on purpose defined rather loosely as “instances in which the students themselves find out answers about nature through some kind of methodical study,
experiment, field observation or similar”. The intention was not to define too rigidly what could count as inquiry to these teachers.

By framing the interviews around actual examples that they used in their own teaching, the aim was to situate the conversations close to their classroom practices to avoid the inclusion of too much romancing in the teachers’ accounts (Kvale, 1996). By centering the interviews on concrete examples provided by the teachers from their own teaching units (books, hand outs, etc.), the conversations were situated close to their actual practice. As conversations between a teacher and teacher educator, the interviews were also situated within the broader context of teacher education, that is, the talk analysed in these interviews is the type of discourse that teacher educators and authors of curricular materials have to relate to.

The interviews were semi-structured, meaning that they were structured around the examples provided by the teachers and a set of tacit questions that guided me during the conversations. Asking a predefined set of questions to each respondent would suggest certain types of answers and exclude others, and was considered too guided. These methodological considerations were inspired by Cobern and Loving (2000), who used a similar approach in a study on teachers’ enacted worldviews.

To further ensure the focus remained on their actual classroom practices, the interviews took place at each teacher’s school, often in the science classrooms they used. Although a specific set of questions was not used, I had a template containing the questions, themes and concepts that I hoped to address during the interviews. Different aspects of this heuristic tool are emphasised in the method sections of Paper I and II, and can be summarised as follows:

1. What is the example about?
2. How is this example motivated as a part of this teacher’s teaching?
3. What are the intended knowledge goals for the students?
4. In what ways does this example relate to key dimensions of inquiry?
5. What terms are important in the descriptions of inquiry as a part of the teacher’s practice?
6. What meaning does the teacher give to these terms?
7. What function do these terms have as a part of their teaching?

Based on my reading of the literature in science studies I summarised a number of characteristic aspects of scientific inquiry that formed the basis for five categories of terms that I hoped to discuss with the teachers as part of questions five and six above. This background is presented in more detail in Paper II, and the following merely summarises the resulting list of inquiry-related terms:
During the interviews, I attempted to stay close to the teachers’ examples and to understand them and issues related to inquiry without losing touch with the context of the teachers’ practice and their own way of describing their work. After having established this context and getting a good sense of the teachers’ own ways of describing it, as well as their own ways of using inquiry-related terms, I ventured into more probing and questioning themes. In doing so, I also presented some of my own ideas more explicitly to hear the participant’s views on these. One such example is when I asked about the difference between an experiment and a laboratory task (Paper II). Care was taken, however, to stay within the limits of the relevant context and example, in order to avoid asking these questions “out of the blue”.

Data compilation
The interviews were recorded digitally and transcribed verbatim. The transcripts were proofread to ensure a high quality of the transcribed record (Kvale, 1996). In the next step, the transcripts were condensed into first-person narratives to be read as if the teachers themselves were describing, without interruptions, pauses or detours, the main examples and themes discussed in each interview (Cobern & Loving, 2000). Care was taken to retain the original wording of the teachers during the interviews, while at the same time making it a more readable text. Although some quotes from the narratives in Paper I may seem slightly unusual, this is a result of an attempt to stay close to the spoken language; it is not an artefact of the translation into English. The resulting narrative summaries were one to two typewritten pages, whereas the actual transcripts were generally 10 or 15 pages. The teachers were then asked to read the narrative summaries and comment on any changes they felt would be necessary for the summaries to be “fair” and something that they felt comfortable endorsing. This procedure was done to increase validity and thereby get a more authentic record of how these teachers described their practice. The narrative summaries were used as the main data source for the results presented in Paper I, while the original transcripts were the main data source for Paper II.
Study 2: Focus Group Interviews

Study 2 was designed and conducted as a continuation and expansion of Study 1 (see Results). The objective was to explore the characteristics of customs in teacher education. As in Study 1, it was a question of achieving a balance between hearing from a number of informants with diverse backgrounds while simultaneously creating space to explore themes in some depth. Focus group interviews were chosen as a way to encompass these diverging considerations. The approach was inspired by recent research on teacher students’ conceptions of their own university education (Volante & Earl, 2002), and university students’ experiences of the culture of scientific research (Hurtado, Carera, Lin, Arellano, & Espinosa, 2009), where focus groups were also used. A useful quality of focus group interviews also proved to be that the informants tend to remind each other of themes, events and topics that could have easily been missed by the interviewer in a dyad setting. On the other hand, a possible complicating factor is that groups can also, as a result of the dynamic between the individuals comprising it, favour certain opinions and silence others. In Study 2, however, this is not as much of a problem, as the object of analysis is not the informants’ opinions, but rather their ways of using certain terms.

Participants

To obtain a broad representation of teacher education programmes in Sweden, focus group interviews were conducted at six well-known universities: Gothenburg University, Malmö University, Mälardalen University, Stockholm University, Umeå University, and Uppsala University. The target group was teacher students who were specialising in science for secondary schools and approaching the end of their education. This criterion was not possible to adhere to completely, as too few students matched these at each university. Therefore, some of the students were not approaching the end of their teacher education, but rather somewhere in the middle. Other students were hoping to work in upper secondary schools after finishing their degree. The majority of the informants did, however, match the criteria. Seven focus group interviews were conducted with three to six students in each, with a total of 32 students. As a token of appreciation for participating, each student received a gift card for a cinema ticket.

Procedure

The students were asked to bring examples to the interviews of inquiry-oriented activities that had been a part of their own teacher education. Most students provided instructions for laboratory tasks or written laboratory reports. Preparations with name tags, coffee and snacks and a relaxed introduc-
tion was arranged in order to create a focused and open conversational climate. As a focusing exercise (Bloor, Frankland, Thomas, & Robson, 2001), I asked the students to agree on a ranking of seven statements, inspired by Roberts’ (1982) curricular emphases, concerning the most common purposes of laboratory work in their own education, as they perceived it (see Appendix B, Paper III). After this, the students were asked to describe the examples they had brought and to specifically focus on the purpose of the activity, as they had understood it. During the course of the interviews, a template was used containing the same terms relevant to inquiry described for Study 1, with a special focus on “hypothesis” and “experiment” that had been highlighted in Study 1 (Appendix A, Paper III). These measures attempted to situate the conversations within the broader context of teacher education, as these were topics that could be discussed between teacher students and teacher educators. The result was highly focused and content-rich conversations, lasting for approximately 1.5 hours. Many students commented after the interviews that they had found them inspiring and educative.

Data compilation

All focus group interviews were transcribed verbatim and then proofread to ensure a high quality of the transcribed record (Bloor et al., 2001). The transcripts were then coded in terms of the general interview topics, as well as sections relating to the use of the terms focused on in this thesis. This provided an overview of the material. In the next step, the transcripts were re-coded in more detail, with a focus on use of the mentioned terms (Kvale, 1996), using the Transana software for qualitative data analysis. The transcripts used in the papers are translations from the verbatim Swedish transcripts to English, and great care has been taken to stay as close as possible to the original sense of the wording. As is often the case with transcribed talk, the results included some grammatically odd formulations. Hence, an extra effort has been made to transfer the same sense of these formulations into English.

Analytical Methods

As a part of the analysis I have developed two analytical tools: pivot terms and a taxonomy of instructional approaches. Pivot terms have been described in the theoretical framework, and will be briefly described here, as they have entered into the analysis processes. The taxonomy of instructional approaches was developed in Study 1 and is described in detail in Paper II, but will be summarised here in relation to the theoretical framework and analytical processes. An analytical distinction used in all articles is also the categories of content in a science curriculum in relation to inquiry, as described in
the Introduction: learning to do inquiry, learning about inquiry and learning canonical science content (called science subject matter in Paper I). Two aspects of learning to do inquiry were highlighted: 1) learning to formulate researchable questions and hypotheses, and 2) learning to design, plan, and carry out corresponding scientific investigations.

Using pivot terms as an analytical tool

The notion of pivot terms grew out of the meeting between the empirical data on the one hand, and my reading of the literature about inquiry in science education on the other, in what could be called a grounded theory approach (Neuman, 2005). The idea was articulated in Paper III based on the findings of Study 1 and 2, and elaborated further with Paper IV. In this thesis, it is presented as part of the theoretical framework, but its empirical grounding should be remembered. After developing the theory of pivot terms, it can now be used in this thesis to also shed light on the findings of Study 1, as presented in the Discussion. In practice, the pivot term analyses in Papers III and IV proceeded in the following way. Once a term had been “suspected” of being a pivot term, it was easy to identify all parts of a transcript that contain or refer to it. Then the process of reading transcripts, coding and sorting was redone with a better structure and focus. After collecting all such instances in which the particular term is used, the task shifted to interpreting the use of this term in relation to the purposes evolving within the interview conversation, as well as in relation to other related discourses and purposes. This demands a certain empathic ability and familiarity with the discourses addressed. Consequently, it becomes important to present a thick description with many examples of transcribed talk so that the reader may validate or refute my own interpretations and inferences (Paper III, IV).

Taxonomy of instructional approaches

To describe the teachers’ examples of different types of instructional approaches in Study I, I constructed a taxonomy of instructional approaches (Table 1, page 48, Paper II). This was inspired by the work of Schwab (1962) and Domin (1999), and 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 laboratory work, and Domin used a similar scheme to define the instructional approaches: inquiry, guided-inquiry/discovery, expository and problem-based. It also reflects, to some extent, the qualitatively different way teachers organise teaching in relation to educational goals. It is an attempt to create a structure for discussing different teaching approaches that has both an internal logic, and is grounded in actual examples taken from the existing tradi-
tion. It is important to emphasise that the taxonomy does not evaluate the different approaches. All approaches may be valid at some point, and the chosen approach must relate to the particular prioritised educational goals and other particulars of any given context. Like other taxonomies and typologies, it offers a simplified structure or map to relate to a more complex reality. As such, it can be used, for example, in discussions amongst teachers or curriculum developers as part of the process of finding a common ground for such discussions. Its usefulness lies in its simplicity as a tool for analysing teaching approaches. The taxonomy was used to categorise the major examples of teaching units discussed during the interviews in Study 1, as presented in Paper I.

Ethical Considerations

The general guidelines of the Swedish Research Council for ethics in research have been followed in this thesis (Vetenskapsrådet, 2002). The informants were provided with written descriptions in Study 1 and 2, both prior to and during the interview occasions, concerning the general research topic and use of the data collected, including anonymity. At the time of the interviews, the participants were asked to sign a statement of informed consent (Kvale, 1996) and were reminded that they could choose to interrupt the interview at any time. Data has been handled confidentially during the research process.

Beyond these formal ethical requirements, a further note can be added. It is possible that some informants, or readers, may feel that the interpretations of some of the provided transcriptions are too drastic, or somehow out of context. However, the nature of the interview conversations analysed in this thesis demonstrates that most of the participants found the issues addressed to be highly relevant and interesting. This means that this research is thus not only a description of the participants and their particular contexts, but rather an exploration with them, into some of the many complex and difficult issues they constantly face.
Summary of Results

As described in the *Theoretical Framework*, issues concerning language and learning, and in particular, the meaning of specific words, must be addressed in relation to some context and purpose. Therefore, it was necessary to begin this thesis project by first trying to describing the context and customs of school science, in other words, the characteristics of school science as a cultural institution, in relation to the notion of “inquiry”. Paper I provides such a description with an analysis of secondary teachers’ own examples of inquiry-oriented teaching approaches and their ways of describing these examples. Paper II is based on the same empirical material and extends the analysis by focusing on the teachers’ use of two particular words found to be especially significant in relation to the educational goal of learning about scientific inquiry, namely, hypothesis and experiment. The results from Study 1 led to questions about the generalisability of the findings, as well as the origins and mechanisms of reproduction of the customs described. These questions were addressed in Study 2, presented in Papers III and IV, and led to further validate the findings of Study 1. They also allowed for a deeper analysis of the relation of various cultural institutions that are significant to understanding the language customs of scientific inquiry in science education. Since a major strength of qualitative research is the recognition of and *feeling* for the situations described, provided by verbatim transcripts, it is recommend (especially anyone not used to this type of research) to read at least some of the transcripts presented in Papers I to IV in order to appreciate the data upon which this summary builds.

Inquiry and the Culture of School Science in Sweden

Paper I explores the existing culture of school science of inquiry-oriented activities (IOA) as instructional approaches. Based on previous attempts to structure the flora of names for various instructional approaches related to inquiry, a taxonomy of approaches was developed and applied to the descriptions of teaching units described by the teachers (Table 1, p. 48, Paper I). This taxonomy, in combination with the three educational goals—learning to do inquiry, learning about inquiry and learning canonical science content—provided the analytical framework for analysing the teachers’ examples. The result is a description of what can be considered typical teach-
ing activities in Swedish secondary schools today that are relevant for discussing teaching and curriculum development related to inquiry. Furthermore, as noted in the Introduction, they may also be relevant beyond a Swedish context (Abd-El-Khalick et al., 2004).

The examples provided by the teachers mainly involved practical tasks that the students worked with for one lesson or less. The educational goals expressed by the teachers included exemplifying a scientific concept (e.g. density) or theory (e.g. heat expansion), providing experiences of certain phenomena (e.g. earthworms), making theoretical tasks more concrete and linking them to real life experiences (e.g. calculating one’s pressure on the floor), varying the teaching, fostering curiosity, and having fun in science class. In summary, the dominant goal of all of these examples is canonical science content. Examples of instructional activities with all degrees of freedom were discussed, although lower degrees dominated (Table 2, p. 52, Paper I). Learning to do scientific inquiry was rarely addressed explicitly, and learning about scientific inquiry was an explicit teaching aim in only two of 18 examples analysed. However, these two only touched upon this subject very lightly. The essential idea, that scientific inquiry starts with a question and that this is the organising principle, was not emphasised by any of the teachers, and was completely absent in most accounts.

Paper I also includes an analysis of the teachers’ reasoning about IOA as part of their own teaching. IOAs were considered valuable and worthwhile by many teachers, but simultaneously problematic and difficult to administer. They were often considered to be fun and beneficial for helping students to better learn and remember canonical science content. In addition, IOAs were associated with a high degree of freedom and thought to stimulate students to think more independently. Table 3 on p. 55 in Paper I is a compilation of the various descriptor terms the teachers often used when discussing different teaching approaches related to inquiry. These descriptors demonstrate what seems to be a rather crude dichotomy between didactical and discovery teaching in the existing school tradition. What this means is that the variety of teaching approaches described in Paper I does not seem to be accompanied by a professional language to talk about these, resulting in difficulties to discuss and compare educational approaches in detail. There was also a tendency to associate IOA with using students’ own spontaneous curiosity as the starting point for instruction. However, this was also one of many aspects of IOA that was considered problematic. IOAs were considered difficult to administer and potentially unsafe for this reason. The general association with IOAs and “hands-on” activities led some teachers to conclude that they were unfit for more abstract topics such as the particle theory of matter. Problems raised by the teachers also include the wide range of abilities in each class and the general limitations of school organisations. These constraints are in line with what previous research has described. An observation not described earlier (to my knowledge) was also the students’
uneasiness about formulating their own hypotheses, in the sense of a guess about an outcome (see Paper II and III), that I have labelled “hypothesis fear”. This issue is addressed in more detail in the Discussion.

Summarising these findings, it seems clear that a wide variety of teaching approaches exist in the customs of school science that could provide experiences to reflect explicitly on the nature of scientific inquiry, but that explicit knowledge goals in terms of learning about scientific inquiry are unusual in this context. The problems associated with IOA seem to be the conflict between using a teaching method characterised as free, open and spontaneous to teach young learners a fixed set of scientific theories or laws, i.e. canonical science content. The limited resolution in the ways of talking about different teaching approaches may contribute to the problems teachers associate with IOA. These results also suggest that IOA will remain problematic unless learning about and learning to do scientific inquiry are given more emphasis as explicit educational goals.

Methods of Teaching or Methods of Scientific Inquiry?

Paper II focuses on the teachers’ use of inquiry-related terminology. Talking about inquiry using the terms described in the Methods section with the teachers in Study 1 proved to be more difficult than anticipated. The teachers were more focused on the pedagogical aspects of inquiry and on learning goals in terms of exemplifying natural phenomena and motivating explanatory models (i.e. canonical science content), than discussing the processes of scientific inquiry. Although I attempted to probe and connect the terms on the list of inquiry-related words to the teachers’ examples, sometimes asking about their use and function explicitly, surprisingly few of these seemed natural to the teachers. In fact, the teachers only spontaneously mentioned two of the terms on the list when discussing their examples: hypothesis and experiment.

The term “hypothesis” was the only one that all of the participants (except one, Paper II) said they used when talking to their students. All of the teachers used “hypothesis” to mean an educated guess about what might happen when doing a laboratory task or exercise. The term was given an important role, and the students were often asked to state their hypothesis as a regular part of laboratory work. The function given to this term by the teachers was synonymous with that of a “prediction”, although this was not a term that any of the teachers volunteered. In six of the interviews, the teachers were explicitly asked whether “prediction” was a word they used, and the answer in each case was “no”. This is not very surprising given that their use of the word “hypothesis” made “prediction” superfluous, as one of the teachers also noted.
Although the teachers used the term “hypothesis” in a way different from authentic scientific inquiry, they used it with a certain kind of rationale, that is, as a pedagogical tool. The teachers described using the hypothesis as a call for students to take a stand or commit themselves to a guess as to the results of the laboratory task. For instance, the result may be some kind of measurement, as in the case of the temperature of boiling water, as exemplified by one teacher, or the nature or development of whatever is being studied. Several of the teachers pointed to the importance of students trying to connect to their initial hypotheses when writing a laboratory report. Thus, the meaning given to “hypothesis” continues to structure the students’ activities when the practical part of the laboratory work is complete. The teachers described asking the students to formulate a hypothesis (an educated guess about an outcome) before performing a laboratory task, primarily to help the students learn the particular subject matter involved in the task. The pedagogical motivation is that it helps the students to focus on what they are doing and remember the science content that the laboratory task is intended to illustrate. Furthermore, it draws the students’ attention to their own preconceptions or how well they have understood the theoretical content being exemplified. Hence, it can also be considered a way of creating conditions conducive to an “aha” experience if the results are contrary to those expected. These more theoretical arguments based on ideas about how students learn have many references to constructivist ideas of learning, which will be presented in the Discussion.

The other term that emerged as important in the conversations with the teachers was “experiment”, and its use as synonymous with “laboratory work” or “laboratory task” (Paper II). The teachers tended to use the term in an everyday sense as synonymous with “testing”, “trying”, or doing something “without knowing what will happen”. This contradicts the technical meaning of “experiment” in scientific research. In line with this every day use of the term “experiment”, learning about and learning to do controlled experiments seemed to be unproblematic for the teachers; it was not distinguished as a conceptual content in need of explicit teaching and learning. In fact, only two of the teachers in this study mentioned very briefly goals in terms of learning about scientific inquiry. This suggests that even though teachers may occasionally have such aims, they are not given a high priority. These two teachers also did not differentiate between the terms “experiment” and “laboratory work”.

Reflecting on how the terms “hypothesis” and “experiment” are more commonly used in scientific research (see Theoretical Framework) inspired me to distinguish between two different categories in which these words seem to play very different roles: methods of teaching, and methods of scientific inquiry. I do not claim that the teachers, when they use the terms “experiment” or “laboratory work”, actually have in mind either a pedagogical strategy or a particular research method such as a controlled experiment,
although it is possible. The point is that there is nothing to suggest that they differentiate between the notions of an experiment and laboratory work in terms of methods of teaching or methods of inquiry when they discuss their teaching. This distinction is introduced to understand how and why the teachers mix these terms and seem so perplexed when asked about them. From the theoretical perspective adopted in this thesis, the meaning of a word is in its use in a particular situation. Thus, in the situation of a teacher talking with a teacher educator and researcher about inquiry, the terms “experiment” and “laboratory work” have the same function and meaning. Seen from the perspective of the educational goals associated with inquiry, this constitutes a conflation between means and ends, where what should have been an educational outcome (language to reflect upon and an understanding of the nature of scientific inquiry) is used as a means to reach a different educational outcome (canonical science content).

Connecting Study 1 and Study 2

The results from Study 1 naturally lead to three questions:

1. What are the consequences for students learning in the classrooms of the conflation between methods of teaching and methods of scientific inquiry?
2. Are the customs analysed and described in Study 1 more widespread or were the teachers interviewed in Study 1 unrepresentative?
3. If the customs are indeed widespread, what might be the origin of this conflation?

I chose to focus on the last two questions in Study 2. The reasons were both guided by research interest and practical circumstances. First, it was considered important to have more data to establish the reliability of the results from Study 1 to a higher degree. The practical circumstances concerned the amount of time and resources available for the second study. However, the question of students’ learning in the classroom was touched upon indirectly. Study 2 focused on teacher students’ experiences with inquiry-oriented activities as part of their own teacher education, with the same focus on inquiry-related terminology as in Study 1. Since the terms “hypothesis” and “experiment” were found to be particularly interesting in Study 1, I have focused on these in the analysis of the focus group data with teacher students, as presented in Papers III and IV.
The Role of “Hypothesis” in Teacher Education

In Paper III, the conflation between methods of teaching and methods of scientific inquiry is labelled the inquiry emphasis conflation and connected to the idea of pivot terms. The focus is on teacher students’ use of the potential pivot term “hypothesis”. This term was used in several ways by the teacher students. “Hypothesis” was equated with a research question, an assumption that can be tested and even exemplified on one occasion by a tentative explanation. However, the most salient use was to equate a hypothesis with a guess about an outcome when performing a laboratory task. It was also clear that the students had not noted the fact that using the word ‘hypothesis’ in this way equates a hypothesis with a prediction. These findings were in line with those of Study 1 (Paper II).

Three different customs of using the term “hypothesis” were found, and related to four different contexts, which can be conceptualised as cultural institutions relevant for teacher education (Table 1, p. 26, Paper III). These four institutions are scientific research, pure science courses, science education courses for teachers, and school science. Scientific research refers to basic or applied research at a university or the equivalent with the aim of increased or better knowledge of natural processes and phenomena. Pure science courses are given by a science department at a university, often led by an active researcher, and with no particular orientation towards teacher education. This type of course tends to focus quite exclusively on introducing students to a well-established body of scientific knowledge. Science education courses for teachers, on the other hand, are given by the teacher education department or the equivalent, and are often led by teachers with a lot of experience teaching science in schools. This type of course often has the dual purpose of teaching students science while also teaching them how to teach science in schools (sometimes called “parallel processes”), although the emphasis between these two purposes may vary. School science is science taught as a school subject in secondary and upper secondary schools.

The custom of having students formulate their own hypotheses as guesses about the outcome of a laboratory task in school science (also described in Paper II) is in stark contrast to the customs of the pure science courses. In these courses, talk about hypotheses is rare, and it is normally not an important concept in laboratory tasks. The absence of hypotheses in laboratory tasks in pure science courses is also accompanied by what seems to be a rather low emphasis on discussion about the nature of science and of scientific inquiry in general. Although hypotheses are rare in pure science courses, some examples discussed during the interviews that can be said to involve hypothesis testing more explicitly. However, these constituted rare and more comprehensive tasks in which the students were given more freedom and responsibility to conduct their own inquiry projects (often encountered only once during the span of their entire university education).
The absence of an emphasis on and discussion of hypotheses in laboratory tasks in pure science courses was contrasted by science education courses for teachers. In the context of science education courses for teachers talk about hypotheses was common and often mixed with talk about theories of learning. This pedagogical use of hypotheses seemed to be taken for granted and not reflected upon critically. It seemed as if it is only in this context of a pedagogical approach to teaching the products of science that the notion of a hypothesis is common and has a familiar role and function for these students.

Students also reported observing what I have called “hypothesis fear” (Paper I); that school students often felt frustrated or uneasy about formulating their own hypotheses as a guess about an outcome. In relation to this, one student also related a comment by one of her mentoring teachers during her practicum periods, who, according to her, rejected the use of hypotheses altogether due to this fact.

On some occasions, the conversations led the students to ask questions about the role of a hypothesis in scientific research compared to the more familiar school science and their own teacher education. They noted the paradox in being given a method, in the form of a recipe to follow in a laboratory task, and then being asked to guess what will happen, while everyone involved knows that there is a single answer that is already known and accepted as the correct one. In other words, there is a didactical contract (Brousseau, 1997), and a correct conclusion to reach (Andrée, 2007). However, even though the familiar custom was challenged on some occasions, the students continued to show a certain loyalty to the customs of school science. Thus, it seems as if the school custom, in part as a result of the practicum periods, exerts a strong pressure on the students, and that they tend to reproduce this custom.

The Role of “Experiment” in Teacher Education

Paper IV extends the analysis of the focus group interviews to determine whether the use of the word “experiment” in science teacher education in Sweden follows a similar trend as the use of the word “hypothesis” described in Paper II and III. This analysis shows that the term “experiment” is habitually used as synonymous to “laboratory task” and equated more or less explicitly with a method of teaching rather than a method of scientific inquiry, in line with the previous findings. When asked specifically about the meaning of “experiment,” this term was given everyday connotations such as “trying” or “testing” in a non-technical sense. When the students were asked about any difference between an “experiment” and a “laboratory task,” they made some probing associations to distinguish the two, for instance, calling an experiment something “small and cute”, more “fun”, “free”, “playful”, “shorter” and “simpler” in comparison with a “laboratory task”. On the other
hand, the latter was often described as more “comprehensive”, “structured” and “serious”. Only on one occasion did one student speculate about the difference in terms of relating an experiment to a research activity and contrasting this to a laboratory task as an educational activity. These findings were consistent in all seven groups interviewed.

An “experiment” was never explicitly associated with a particular methodology for producing new knowledge about causal relationships. The notion of a “controlled experiment” seemed to be unheard of by most students, or at least appear unusual. The related notions of “dependent” and “independent variables” were vaguely recognised by some students as relating to potential sources of error that may help to explain deviations from the expected result. Both “experiment” and “controlled experiment” were associated with reaching or producing an “expected result”. It seemed as if the notion of “control” was somehow associated with the level of control the teacher or task exerts upon students in an educational setting. In spite of my attempts to focus on issues related to the nature of scientific inquiry, the students habitually used the terms analysed in this article in the context of educational activities, or in an everyday sense, as opposed to the context of research activities.

According to the students, and judging by the quality of the conversations analysed, topics concerning meta-knowledge about scientific inquiry had not been discussed explicitly during their university education. In particular, they had not discussed the characteristics of an experiment and why and when it is an appropriate method to use. Rather, they were very focused on the “hands-on” aspects of laboratory work as an educational activity with the goal of teaching canonical science content. Also, in several cases, the students perceived the main purpose of inquiry-oriented activities or laboratory tasks as illustrating how they could later work as teachers in schools. However, as the transcripts show (Paper IV), these interviews made some students aware of an unfulfilled need for discussing these topics explicitly. The students also began to acknowledge the importance of how teachers talk and issues of language in science teaching.

Main Findings

Below the most salient empirical findings are summarised. All items on this list refer both to secondary schools and teacher education programmes unless stated otherwise. The first four main findings answer the first overarching research question: How are existing traditions and customs of teaching science related to the educational goal of learning about scientific inquiry? Numbers five to ten answer the second overarching question: How is inquiry-related terminology used in science education settings such as schools and teacher education programmes?
1. An explicit focus on teaching about the characteristics of scientific inquiry is unusual.

2. The notion of “research question”, central to scientific inquiry in the science education literature, is not used to structure inquiry-oriented teaching activities.

3. There exists a wide variety of teaching approaches in the school tradition that could provide experiences to reflect explicitly on the nature of scientific inquiry. However, this variety is not accompanied by a well-defined professional language to discuss and differentiate between these approaches in relation to educational goals.

4. Inquiry-oriented teaching approaches (IOA) are often considered by teachers to be valuable and worthwhile, but simultaneously problematic and difficult to administer.

5. The term “hypothesis” is primarily used as synonymous with “prediction” in the sense of “a guess about an outcome” when performing laboratory tasks.

6. The term “experiment” is used as synonymous with “laboratory task”, and in an everyday non-technical sense of “trying” or “testing”, and “without knowing what will happen”, in contrast to “controlled experiment” as a method of scientific research.

7. Both “hypotheses” and “experiment” are used with a primarily pedagogical function as part of the methods of teaching canonical science content.

8. The pedagogical use of “hypotheses” is associated with “hypothesis fear” amongst school students.

9. Science courses at the university level tend to either reinforce the school customs of using inquiry terminology in a pedagogical sense, or remain silent about it (in contrast to the emphasis on correct terminology in learning canonical science content).

10. Teacher students show a tendency to align themselves with the customs of school science in the pedagogical use of inquiry-related terms, rather than learning using these as part of a discourse of scientific research.
Discussion

The findings presented in this thesis support the description of the confusion regarding inquiry in science education summarised in the Introduction. They also address how the specific problem of learning and teaching about scientific inquiry can be approached by an analysis of the role of language and the use of particular words in science education. Based on this analysis, some suggestions can be given about how to overcome this problem, which includes pointing to some possible origins. This discussion will form an answer to the third overarching research question mentioned in the Introduction: How can relevant distinctions concerning customs and language use be made explicit for reflection? Directions for further research will then be discussed briefly. However, before developing these themes, some methodological considerations are needed to appreciate the nature of these findings.

Methodological Considerations

The conversations analysed here need to be understood in terms of their situated nature (Barab & Plucker, 2002; Bloor et al., 2001; Kvale, 1996), that is, as situated within a context of science teacher education. This means that it is likely that the teachers and teacher students could talk to and understand a research scientist in a different context, for example, when visiting a lab or watching a TV show, describing his or her work with “experiments”, “hypotheses” and the need to control variables. The point is that they do not make these distinctions explicit in the context of science education, that is, in a conversation with a teacher educator about the purpose of inquiry-oriented or laboratory activities. The fact that these interviews are situated within a context of teacher education adds to the validity of the results when used in the same context. In other words, they can be directly useful to guide instruction in science teacher education. Simultaneously this also means that one must be careful about inferring consequences for students learning in school classrooms. However, this question is indirectly addressed by considering the fact that both the teachers and the teacher students have had a long exposure to the existing school customs (Lortie, 1975). Thus, if the teachers and teacher students interviewed here have been exposed to these same customs, one consequence seems to be that they have acquired language habits that
hinder them from discussing and thus also noticing aspects important for teaching and learning about the characteristics of scientific inquiry.

The reliability of the findings concerning the use of the inquiry-related terms “hypothesis” and “experiment” can be considered high, at least nationally. Very few discrepancies from the main findings presented here were encountered in the entire empirical material consisting of in-depth interviews with 44 individuals with diverse backgrounds. The same can be said for the relative absence of learning about scientific inquiry as an explicit educational goal. Less obvious are the reported observations of what I have called “hypothesis fear”. The significance of these comments was realised after the completion of the data collection and was therefore not addressed explicitly during the interviews. Twelve of the respondents made explicit comments relating to “hypothesis fear”, which may be considered a small sample. However, the findings can also be considered even more interesting precisely because I did not ask about this explicitly. The teachers’ examples of inquiry-oriented teaching approaches also comprise a relatively small sample. However, they have been corroborated as a representative description of the existing tradition by other teachers, teacher educators and researchers when presented with these at seminars and professional meetings. Given the qualitative nature of this thesis and limited number of respondents, I believe that the purposive selection of these has nevertheless resulted in a group of students and teachers that are representative of these populations in Sweden to a high degree, giving room for a certain amount of generalisability of the results. Ultimately, however, the test of the true relevance of these findings is based on the recognition and validation made by each reader of this thesis by taking part of the actual interview transcripts and the detailed analyses of these.

Defining the Problem: The Inquiry Emphasis Conflation

The answers presented to the first two overarching research questions of this thesis (see Main findings) constitute a set of problems identified within the existing customs in science education in relation to teaching and learning about inquiry as an educational goal. The first problem concerns the existing customs of teaching approaches and their relation to this educational goal, and the second problem concerns customs of language use. It is necessary to discuss the nature of these problems, as well as some possible origins, before suggesting solutions.

Previous research has identified some of the same problems associated with “inquiry”, as identified in this study, such as the institutional constraints of school science (Anderson, 2007), that “inquiry” is an ambiguous term (DeBoer, 1991), and that learning about inquiry is an unusual goal (Hult, 2000; Högström, 2009; Högström, Ottander, & Benckert, 2005; Löfdahl,
The findings presented here suggest that the problematic nature of IOAs described by the teachers in Study 1 seem to stem from the conflict between perceiving them as free, spontaneous, open-ended, discovery teaching, and the dominant goal of teaching students a fixed curriculum of primarily canonical science content (Paper I). The focus of inquiry as a pedagogical strategy in science education (Bybee, 2000) seems to result in IOAs only being favoured based on the belief that if done well, they will help the students to remember the canonical content better and perhaps make science education more enjoyable. These findings suggest that IOAs will remain problematic as long as learning about scientific inquiry is not emphasised as a distinct and explicit educational goal, and as long as they are defined one-dimensionally as free and open in contrast to traditional and structured laboratory tasks.

A prerequisite for learning in institutional practices such as school science is that learners are given access to a relevant discourse (Bartholomew et al., 2004; Bergqvist & Säljö, 1994; Wickman & Östman, 2002). What teachers are able to notice, and therefore teach in science, depends on how they use language to make certain distinctions. Students learn about scientific inquiry by gaining access to words like “experiment” and “hypothesis”, using them in action, and communicating and thinking with them in contexts in which they have consequences and become meaningful. Some teachers in Study 1 expressed how they considered it important that the students learn “the correct language of science” and use words in their proper scientific sense (Paper II). This concern about teaching students the correct use of scientific terms (i.e. canonical content) contrasted sharply with the teachers’ and teacher students’ seemingly unreflective use of inquiry-related terms; both used the terms “hypothesis” and “experiment” in ways that conflate the categories of methods of teaching and methods of scientific inquiry (Paper II, III, IV). The dominance of the educational goal of canonical science content then makes these terms fall functionally into the category of methods of teaching. If this goal is the only objective of science education, this is not a problem. However, in order to learn about scientific inquiry, these terms are needed conceptually as a part of the category of methods of scientific inquiry. I have labelled this problem the inquiry emphasis conflation. The following section will address two specific problematic consequences that can be a result of the inquiry emphasis conflation, although there may be more. The first is the “hypothesis fear” reported in the findings of this thesis, and the second concerns three aspects of learning about the NOS described in the science education literature.

The problem of “hypothesis fear” seems to stem from the pedagogical use of “hypotheses” in combination with the tacit didactical contract (Brousseau, 1997) characteristic of school science. The didactical contract states that what is important to learn are the correct explanations and producing the correct results (Andrée, 2007) in a laboratory task, i.e. the focus is on ca-
nonical content and not on learning about scientific inquiry. As these explanations and results are known, there is no incentive for students to take a guess that turns out to be incorrect because of the risk of appearing stupid. This risk and the prospect of wasted intellectual effort combined with a desire to please the teacher can be hypothesised to produce the anxiety reported amongst students. These problems 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.

Learning about scientific inquiry is closely related to learning about NOS. Lederman has described a set of seven characteristics of NOS that are relevant and teachable to secondary school students, and regarding which there is little controversy amongst scholars in science studies (Lederman, 2004). Here I discuss how three of these characteristics may be affected by the inquiry emphasis conflation: understanding the distinction between an observation and an inference, that scientific knowledge is theory-laden, and that scientific knowledge is based on empirical data.

Drawing inferences from empirical observations often entails reference to the tentative explanatory propositions stated in a scientific hypothesis. If the “hypothesis” is conflated with a prediction and used mainly as a pedagogical device, this connection is obscured. Organising enquiries around simple predictions without attempting to construct possible explanations or models will not promote reflection about the connection between claims and evidence. The fact that scientific knowledge is theory-laden is associated with understanding the creative dimension involved in formulating hypotheses as possible explanations. The formulation of hypotheses and the associated design of investigations to test these are based on theoretical assumptions and the results of previous enquiries, which is the essence of theory-ladenness. As Lederman (2007) puts it, “Science involves the invention of explanations” (p. 834). An exclusive focus on predictions at the cost of understanding the role and function of hypotheses as an attempt to explain phenomena reduces the creative element of science to some sort of fortune-telling. This also obscures the role of hypotheses in the construction of models in scientific inquiry (Windschitl et al., 2008). That scientific knowledge is based on empirical data indicates the need to understand the nature of adequate evidence to support scientific claims (O'Neill & Polman, 2004). A controlled experiment is an example of a structured method of empirically deciding whether a hypothesis, as a tentative explanation of a phenomenon, is fruitful. An experiment (as a method of scientific inquiry) is, in this sense, completely different from conducting a laboratory task (as a method of teaching) in order to, for example, illustrate or validate some part of the canonical science content (Paper IV).
The problematic nature of the findings reported here can and has been questioned. One reviewer of Paper II asked if a certain intertwining of pedagogical and “authentic science” interpretations of inquiry might actually be desirable in the classroom, given the difference between these activities and their participants’ knowledge and goals. My argument is that it is precisely because the activities of scientists and students in the classroom are so different in terms of knowledge and goals (Metz, 2004) that the distinction between methods of teaching and methods of scientific inquiry must be clarified. The same reviewer also suggested that if scientists were interviewed, it is probable that they might not always express clear distinctions regarding the terms analysed in this paper. I agree; however, if philosophers and historians of science were interviewed, they would most likely agree with the distinction made here. The key is to remember that the educational goal of learning about inquiry concerns meta-knowledge about the practice of science, and is thus the domain of scholars of science studies. Practicing scientists are normally not concerned with studying the practice of science, but rather the workings of nature. School science does not only involve teaching students the results of science, but also the results of science studies, that is, learning about scientific inquiry and NOS.

Origins and Reproduction of the Inquiry Emphasis

Conflation

Mediated action is shaped by its developmental path, which means that it needs to be considered in relation to the historical and contingent elements of the sociocultural context in which it occurs (Wertsch, 1998). In order to understand the significance of a pivot term such as “hypothesis”, it is therefore important to examine the origins and development of its use. Doing so indicates that there is reason to believe that the inquiry emphasis conflation in school science is connected with the influences of constructivist theories of learning.

The production and consummation of cultural tools often results in unanticipated “spin-off effects”. Wertsch (1998) summarises this characteristic of cultural tools and mediated action as follows:

(1) the cultural tools that mediate human action may not have evolved for the purposes they have come to have and (2) in many cases the concrete cultural tools used have been borrowed from quite distinct sociocultural contexts. In a sense, then, we often “misuse” tools, and this may have the consequences that our action is shaped in ways that are not helpful or even antithetical to the expressed intentions and assumptions of agents about the design of the tools they employ. (p. 63)
A pivot term can thus be said to be misused in one context if it creates constraints unwanted in relation to the objectives of its activities, as exemplified by the pedagogical use of “hypothesis” in relation to the objective of learning about scientific inquiry. The constraints and affordances provided by mediational means are difficult for users to perceive at the time of the conception of a new tool, and are only noticed in retrospect when the perspective changes, or when moving from one cultural context to another, again formulated here by Wertsch (1998):

until we learn, or at least hear about, a second language we are quite unlikely to be aware that our native language has fundamental constraints built into it […]. The point is that by using the cultural tools provided to us by the sociocultural context in which we function, we usually do not operate by choice. (p. 55)

One objective of educational research is to draw attention to what we normally do not notice and thus take for granted, and thereby helping agents to “operate by choice” to a larger extent.

Constructivist theories of learning can be traced to Piaget’s theory of individual development of cognitive schemata through a process of accommodation resulting from a loss of mental equilibrium (Piaget, 1964/2003). Piaget’s theory and its early elaborations to suit the field of science education research tend to mix theories of how individuals learn on a short time scale, and theories of how science as a collective enterprise advances over the course of hundreds of years (Carey, 1999; Driver & Easley, 1978; Posner, Strike, Hewson, & Gertzog, 1982). Park (2006, p.488) recently summarised teaching based on constructivism as being composed of four stages: ‘recognition of prior idea, cognitive conflict, resolution of conflict, and recognition of the modified idea.’ Somewhere along the way, the notion of hypothesis seems to have been hijacked as a tool for eliciting students’ prior ideas and setting the stage for a cognitive conflict to occur. In this process, the hypothesis has become confused with a prediction, and since the objective has not traditionally been to teach students about scientific inquiry, this collapsed distinction did not appear to have any negative consequences. However, if an understanding of scientific inquiry is important, this conflation becomes problematic. This pedagogical use of “hypothesis” seems to be the cause of the reported “hypothesis fear”, as already described. These interpretations are in line with other critiques of constructivism that address its epistemological and ontological basis (Kruckenberg, 2006; Säljö, 2000), and the pedagogical practices derived from it (Caravita & Hallidén, 1994; Furtak, 2006). Furthermore, the idea that students’ misconceptions always obstruct learning and that teachers therefore need to focus primarily on conceptual change has recently been criticised (Hamza & Wickman, 2007).
It is of course possible that there are other origins of *the inquiry emphasis conflation*. One is that scientists and science textbooks may not always use these terms in a perfectly consequent manner (Lawson, Oertman, & Jensen, 2007). Scientists working within the culture of science may not need to make these distinctions explicit, since it is often evident from the wider context and overarching goals and objective what is meant when discussing technical aspects such as those concerning research methodology. In line with the above quote by Wertsch, customs and traditions are largely unexamined by the members of a cultural institution (Dewey, 1930). We are, to paraphrase Gurdjieff (1992), as accustomed to them as to our own smell. It is in the crossing over from one context to another, as when moving between scientific research to school science, that pivot terms appear and may become significant. This is similar to how people tend to become aware of the idiosyncrasies of their own culture only when they travel abroad and gain another perspective. This also explains why scientists may work successfully for an entire career within science without ever having to confront these cultural border crossing issues, while they are at the core of teaching science, which involves introducing learners to the language games of a foreign cultural institution.

Regardless of how *the inquiry emphasis conflation* has come into being, it continues to be reproduced. Teacher students often gain most of their experience with science from college courses. As indicated in this thesis, college courses in the natural sciences rarely go into any depth in teaching about scientific inquiry and NOS (Paper III, IV), which is in line with previous studies (Bartholomew et al., 2004). However, even students with experience of authentic scientific inquiry are often not used to reflecting on the role of theories, models, and hypotheses in scientific inquiry (Windschitl & Thompson, 2006). Paper III and IV demonstrate how the custom of using the terms “hypothesis” and “experiment” seems to be reproduced in school science with little or no influence from the customs of scientific research passing through the filter of teacher education. Similarly, Windschitl (2004) found that teacher students tend to reproduce a “folk theory” of what it means to do scientific inquiry. The students interviewed in Study 2 of this thesis have a significant amount of experience of doing laboratory tasks during their education, both in school and at university, but in line with the previous findings mentioned (Schwartz et al., 2004; Trumbull et al., 2005), they have in spite of this, not developed habits for reflecting on the nature of scientific inquiry as a research activity. Given that these habits are not developed “naturally” by exposure to inquiry, teachers need to help students at all levels to reflect explicitly on these issues.

Pure science courses were generally found to omit discussions about hypotheses and the nature of scientific inquiry (Paper III). However, it is not merely what is said and done that is important in education, but also what is not said, what Östman (1998) called “companion meanings”. Thus, the pure
Science courses indirectly teach that talk about hypotheses in relation to research methodology and scientific inquiry is not important enough to merit systematic teaching and assessment. The link between scientific research and the rest of the educational system is broken by the silence about these issues. Consequently, the pure science courses contribute to maintaining the status quo. On the other hand, science education courses for teacher students seem to import the school tradition right into the university (Paper III). Here, laboratory work is used both to illustrate science topics and teaching methods simultaneously (the so-called “parallel processes”), thus contributing more directly to reproducing the inquiry emphasis conflation. In these courses, talk of hypotheses and experiments seems common, but is also taken for granted and not reflected on explicitly. These terms are primarily used as pedagogical tools rather than as concepts of research methodology. The “hypothesis” is connected to theories of learning and teaching methods (i.e. constructivism), but not to discussions for learning about scientific inquiry. Thus, methods of teaching are not separated from methods of scientific inquiry, and the inquiry emphasis conflation is perpetuated. This state of affairs is probably not intended by the teachers leading these courses; however, if these issues have been raised, they have not had much impact judging by the results presented in this thesis.

Suggestions for Teaching and Curriculum Development

Customs and traditions, including language uses, have a momentum of their own and are interwoven with many dimensions of cultural institutions, thus making them difficult to change (Dewey, 1930; Hodgson, 2007; Maréchal, 2010). However, the results of this thesis can be used as a point of departure for discussing the similarities and differences between school science and authentic scientific research, to make existing habits and unexamined assumptions available for explicit deliberation. This may preferably be initiated already at the beginning of students’ university education, as individuals’ habits are more susceptible to change when other major contextual elements also change (Maréchal, 2010). Although learning about inquiry is not the only objective of science education, it is important to emphasise the matching of distinct knowledge goals with distinct teaching methods. The results presented here indicate that if learning about scientific inquiry is a goal of science education in schools, teachers and teacher educators need to become aware of the obstacles identified in this thesis.

This thesis provides six interconnected elements that can be used by teachers, teacher educators and developers of curricular materials as tools for more informed choices and discussions. The first is the identification of the four different cultural institutions relevant for understanding issues of language in science education presented in Paper III. The second is the notion
of pivot terms that can be used to highlight how specific words, easily conflated, are used differently in these cultural institutions and thus mediate different sets of actions (Paper III, IV). The third is the inquiry emphasis conflation, which relates the two categories of methods of teaching and methods of scientific inquiry to the educational goal of learning about scientific inquiry (Paper III, IV). These results can be considered a basis for taking teachers’ voices into account in the development of curriculum materials (Trumbull et al., 2005). Specifically, the idea of pivot terms and their relation to the discourses of cultural institutions can help develop a mutual language for overlapping cultures relevant to science education (Keys & Bryan, 2001). The fourth element is the tree diagram presented in Paper IV (Figure 1, p. 24, Paper IV) as a heuristic tool to help illustrate the inquiry emphasis conflation. The fifth is the taxonomy of instructional approaches (Table 1, p. 48, Paper I), which can be used in conjunction with the tree diagram of Paper IV to expand the category simply designated by “laboratory tasks”. The sixth and final element is the identification of the four educational goals for inquiry-oriented activities within the context of teacher education needed to clarify the purpose of these activities to teacher students, which—in addition to the three goals stated in the Introduction and used throughout this thesis—also include a fourth: learning to teach science (Paper IV). Elements four, five and six can be of particular use to translate experiences of doing scientific inquiry into manageable classroom practices, as suggested by Britner and Finson (2005).

Teacher education programmes need to address the fact that science education courses for teachers tend to reproduce the existing school traditions in an unreflective manner. In particular, there is a need to analyse the various objectives and purposes of laboratory work as part of teacher education (Paper IV). The taxonomy of instructional approaches (Paper I) can be used to clarify the connection between different goals and instructional approaches. Work also needs to be done to distinguish explicitly between theories of how individuals learn and descriptions of how knowledge production occurs in science at large, as the “hypothesis fear” and its connection with constructivism indicate. To overcome this problem in schools, it is suggested that the personalised form of address be abandoned when asking students for predictions and a hypothesis. Rather, there should be a critical examination of all possible explanations (hypotheses) and how they relate to the empirical evidence (predictions and actual outcomes). Pure science courses need to consider the wider implications of omitting serious discussion of epistemological and methodological issues of scientific inquiry. Furthermore, more effort should be devoted to teaching about scientific inquiry and, in particular, the logic of hypothesis testing. In addition to benefiting teacher education, a higher awareness of the methodological issues of scientific inquiry should also be of intrinsic value to any kind of science education, whether for teachers, future researchers, engineers or other. Teachers, teacher educators
and authors of reform documents and curriculum materials need to be aware of the ways in which the customs of school science discourse can deviate from the discourse of scientific research that the education is meant to introduce. If this is forgotten, it is easy to talk past one another and imagine that communication is taking place simply because the same words are being used.

**Further Research**

Having established that the customs analysed in this thesis seem to be widespread, based on the interviews with teachers and teachers students, an important question to follow up in more detail is in what ways these customs shape classroom interactions and student learning. The identification and role played by other potential pivot terms may also be worth researching. Also, the fact that issues related to “inquiry” in science education tend to extend across national borders (Abd-El-Khalick et al., 2004) suggests that the theoretical constructs developed in this thesis may be used in other countries and to compare science education internationally.

One example of another potential pivot term is “theory”, which may be considered a pivot term on the boundary between “everyday conversations” and a discourse of scientific research. One well-known example is its use in the notion of the “theory of evolution,” considered well grounded in science, in contrast to the everyday use of “theory” as something speculative and uncertain (Dagher & BouJaoude, 1997). Still, another example is “research question”, or simply “question”, which can be positioned on the boundary between a discourse of scientific inquiry and a more general school discourse. Lager-Nyqvist et al. (2010) found that the term “question” tended to cause problems in middle-school science classrooms, as students engaged in inquiry-oriented activities and were asked to formulate researchable questions to investigate. In the prevailing school custom, to which the students are accustomed, the teacher asks the questions to probe students’ understanding or knowledge, a custom of formulating questions that is quite different to posing researchable questions to guide scientific inquiry. Other words used in science mainly related to canonical science content such as “energy” or “force” also have everyday non-technical uses. Traditionally, problems associated with these have been addressed in science education research from the perspective of misconceptions, with a focus on individuals cognition. Based on the sociocultural and pragmatist framework, including pivot terms developed in this thesis, these issues could instead be addressed in terms of mediated action and situated learning.

Finally, as most branches of the social sciences are concerned with issues of culture, language and learning to some degree, the idea of pivot terms may find other uses beyond the field of science education. For example, it
would be interesting to explore the relationship between the theoretical development and findings of this thesis to the related fields of linguistics and cognitive linguistics, such as research on polysemy and ambiguity (Nerlich, 2003). In addition, organisational and economic studies concerned with the relationship of cultural institutions and individual action may find these results useful (Cohen, 2007; Hodgson, 2007; Maréchal, 2010). These are just a few examples of other branches of social science that may overlap with this thesis. Although the list could easily be multiplied, the value and meaningfulness of these overlaps can only be decided by further studies.
References


