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Teaching for conceptual understanding in science within an integrated inquiry-based science and literacy setting

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PhD thesis

Berit S. Haug

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Thesis abstract

The main aim of this thesis is to examine how to promote conceptual understanding in science within the context of an integrated inquiry-based science and literacy curriculum. Six elementary school teachers participating in a professional development course were video-taped as they implemented an integrated curriculum. In this curriculum, science inquiry implies that students search for evidence in order to make and revise explanations based on the evidence found and through critical and logical thinking. Moreover, the curriculum material is designed to address key science concepts multiple times through multiple modalities (do it, say it, read it, write it). Large-scale studies on integrating inquiry science and literacy have demonstrated effectiveness in terms of increased learning outcomes in both science and literacy. These studies, however, have not provided insight into the actual teaching and learning process as it occurs moment-by-moment in the classroom. Therefore, the present small-scale video study aims at describing how teachers encourage students' development of conceptual knowledge during the implementation of an integrated curriculum, with an emphasis on key science concepts. The four articles that constitute the core of the thesis address the main aim from different perspectives: integration of science and literacy, formative assessment, vocabulary development, and inquiry-based science.

This thesis is part of a larger research project, the Budding Science and Literacy project. Article I, which is an overview video study of the larger project, demonstrates the variation and patterns of inquiry-based science and literacy activities in six elementary school classrooms. Research suggests that consolidation phases, in which students discuss their empirical findings and teachers help students connect their results to theory, are central to conceptual development. Therefore, Article I contributes important information to the overarching aim by illuminating how much time teachers spend on consolidating students' new knowledge during inquiry. The main aim of this article was to examine how an integrated science and literacy approach challenges and supports teaching and learning science. By studying the occurrence and co-occurrence of literacy and inquiry activities, the patterns indicated where the challenges were and consequently where teachers need support to practice such integration successfully in science teaching. Results suggest that literacy activities embedded in science inquiry provide support for teaching and learning science. However, it was challenging for the teachers to include and use the discussion and communication phases in order to consolidate the students' conceptual learning. The

overview study in Article I forms the basis for the in-depth studies conducted in the three other articles.

In Article II, development of conceptual knowledge is addressed through features of formative assessment. The study examined how teachers identified science concepts that are key to understanding the topic being taught, how they elicited students' understanding of these concepts, and the type of feedback the teachers provided to foster conceptual understanding in students. The article's main aim was to examine teachers' sensitivity to student responses, which was especially related to the feedback provided. Six elementary school teachers were interviewed and video-taped as they implemented the integrated inquiry-based science and literacy curriculum. Findings indicated that elementary school teachers with low level of pedagogical content knowledge in science do not easily identify the key concepts of a scientific idea. Consequently, when the teachers responded to student utterances, the teachers did not focus on the key concepts necessary to promote conceptual understanding. Furthermore, when the key concepts were identified and highlighted in the curriculum the teachers implemented, the teachers often taught the concepts in isolation without encouraging the students to apply the concepts in a context which is essential for conceptual understanding.

Article III explores how two elementary school teachers facilitated students' conceptual understanding throughout different phases of science inquiry. In the integrated science/literacy curriculum the teachers implemented, key science concepts were taught through the development of word knowledge. A framework for word knowledge was applied to examine students' level of word knowledge as manifested in their talk. In this framework, highly developed knowledge of a word is consistent with conceptual knowledge. This includes understanding of how the word is situated within a network of other words and ideas. The results suggest that students' level of word knowledge developed toward conceptual knowledge when the students were required to apply the key concepts in their talk through all phases of inquiry. When the students became familiar with the key concepts through the initial inquiry activities, the students used the concepts as tools to further their conceptual understanding when discussing their ideas and findings. However, conceptual understanding was not promoted when the teachers did the talking for the students, rephrased their responses into the expected answer or neglected to address the students' everyday perceptions of scientific phenomena.

Article IV examines how an inquiry-based approach to teaching and learning creates teachable moments that can foster conceptual understanding in students, and how teachers capitalize upon these moments. The study built on Article I's suggestion that it was challenging for teachers to include phases of inquiry where students consolidated their learning. Therefore, the study identified and explored teachable moments during phases of inquiry in which students were expected to discuss and communicate empirical findings in order to develop conceptual knowledge. Six elementary school teachers were videotaped as they implemented the integrated inquiry-based science and literacy curriculum. Two types of teachable moments were identified: planned and spontaneous. Results suggest that the consolidation phases of inquiry, when the students reinforced new knowledge and connected their empirical findings to theory, could be considered as planned teachable moments. These are phases of inquiry during which the teacher should expect, and be prepared for, student utterances that create opportunities to further student learning. Spontaneous teachable moments occurred when an utterance made by the teacher or a student brought the discourse in a different direction than planned by the teacher and created an opportunity to further students' understanding. Capitalizing on teachable moments in ways that foster conceptual knowledge requires that teachers are sensitive to, and build on, student thinking.

In all four articles, implications are discussed based on the empirical findings and recommendations for improved science teaching are made. Among the recommendations are identifying key science concepts and teaching these concepts in a context of related science words and concepts. Regardless of the pedagogical strategy applied, the key concepts reflecting the subject matter content must be the center of attention if conceptual knowledge is the desired outcome. Furthermore, students must be the active part responsible for the talking, with the teacher scaffolding students' development of the vocabulary required to understand the science content. Also, more time must be allocated to the consolidating phases of inquiry to enhance student learning. In addition to identifying *what* teachers should do to promote student understanding, the articles also provide practice-oriented examples of *how* to teach for conceptual development.

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1. Introduction

1.1 An overview of the thesis

This thesis is about teaching for conceptual understanding in science in the context of an integrated inquiry-based science and literacy curriculum. Topics addressed range from how formative assessment and a focus on development of word knowledge can promote conceptual understanding within the integrated curriculum to the possibilities inquiry-based science generates for science content learning. Data were collected in Norwegian elementary school classrooms; however, the issues discussed in the thesis are not confined to Norwegian elementary school teachers. The questions concern pedagogical approaches relevant for teaching in general and apply to an international audience. A specific contribution to the field of science education is the insight this work offers into the actual teaching and learning process as it occurs moment-by-moment in an inquiry-based classroom. This includes aspects of the teacher–student interaction that support or impede student development of conceptual knowledge.

This thesis is divided into two parts. Four articles constitute the latter part, and the first part elaborates on important questions and places the articles in a broader context. The outline for the first part is as follows: In the introduction chapter, I provide an account for the background and rationale of the thesis, including operational definitions of important concepts, before stating my overarching aim and research questions in section 1.3. Included in section 1.3 is an introduction to the four articles that constitute the basis of the thesis and how they address the overarching aim. Chapter 2 gives an overview of literature important for my research, followed by a chapter reflecting on the theoretical perspectives I build on. With these two chapters, I place my work in the landscape of research on teaching and learning in general and in science education in particular. In Chapter 4, I reflect on the methodological choices I have made and discuss these choices in a broader manner than the format of a journal article allows. This chapter starts with a presentation of the project Budding Science and Literacy that this research was part of, followed by an account of the choice of design, data collection, and analysis. The chapter ends with ethical considerations regarding this research. Chapter 5 provides a summary of the four articles, highlighting the main findings. In Chapter 6, I discuss these findings and place them in the broader perspective of teaching and learning science and in accordance with the overarching aim of the thesis.

1.2 Background and rationale

The integration of science inquiry and literacy into one curriculum is rooted in extensive research. For a long time, inquiry science has been at the center of research among science educators. A growing body of evidence supports inquiry-based instruction as more effective in terms of student learning compared to instruction focusing on knowledge transmission (e.g., Anderson 2002; Hmelo-Silver, Duncan, and Chinn 2007; Minner, Levy, and Century 2010). Policy documents and curriculum materials around the world are developed based on the idea of inquiry-based instruction as the way to improve science education (Abd-El-Khalick et al. 2004; Millar and Osborne 1998; Rocard 2007). At the same time, the direction of interest within science education has moved toward emphasizing how meanings are developed through language, more specifically the language of science (e.g., Cervetti, Pearson, Bravo, and Barber 2006; Lemke 1990; Wellington and Osborne 2001). Thus, combining inquiry science and language instruction in an integrated inquiry-based science and literacy curriculum makes sense. Additionally, several large-scale studies have shown that integrated inquiry-based science and literacy activities foster increased learning outcomes in both literacy and science (e.g., Hapgood, Magnusson, and Palincsar 2004; Pearson, Moje, and Greenleaf 2010; Yore et al. 2004).

In the literature, there is no consensus regarding how inquiry is related to science teaching and learning. Therefore, when inquiry-based science education is discussed, one’s view of inquiry must be defined. In this thesis, the operational definition of science inquiry involves students searching for evidence to support their ideas through firsthand (hands-on) and secondhand (text) investigations. Students also engage in critical and logical thinking to learn how to make and revise explanations based on the evidence found (Barber 2009). Another clarification concerns the different objectives of science inquiry. An inquiry-based approach has the potential for students to learn how to *do* science (process), learn *about* science (nature of science), and learn *science* by doing science (science content) (Anderson 2007; Gyllenpalm, Wickman, and Holmgren 2010). This thesis focuses on the aspect of “learning science by doing science,” more precisely, how teachers teach for conceptual understanding within the context of an integrated inquiry-based science and literacy curriculum.

Literacy is another ambiguous term that requires clarification. In the science/literacy curriculum that constitutes the context for the data collected in this thesis, literacy in science rests on the idea that reading, writing, and talking call for different sets of skills depending on the nature of the text and the disciplinary practices in which the activities are situated (Cervetti 2013; Shanahan and Shanahan 2008). Therefore, to support their own science learning, students need to acquire strategies for understanding and writing science texts and tying the literacy practices of science to science inquiry. This yields a synergy effect as students' literacy development also improves. The inextricable relationship between science and literacy is reflected in Norris and Phillips' (2003) notion of the fundamental and derived senses of scientific literacy. The fundamental sense, which constitutes the basis for the integrated curriculum, involves reading and writing and being fluid in the discourse patterns and communication systems of science. The derived sense involves being knowledgeable and educated in science and being able to take a critical stance on information. Norris and Phillips (2003) argue that without knowledge of the language of science, the depth of scientific knowledge a person can acquire is severely limited.

The role of literacy in this thesis primarily concerns how the teachers support students' development and use of the language of science, mainly through talking. This involves the notion that knowledge of scientific terms provides access to scientific knowledge and written text, thus, helping students enhance their understanding of scientific phenomena (Norris and Phillips 2003; Wellington and Osborne 2001).

The last term that requires an operational definition is conceptual understanding. Conceptual understanding as used in this thesis refers to the understanding of science concepts. More precisely, this means understanding the ideas or phenomena behind concepts expressed through words at gradually ascending levels of abstraction. This requires use of the medium of language and knowing that these words cannot be understood in isolation, they belong to a network where the meaning of one word depends on prior understandings of other words (Wellington and Osborne 2001). To support student learning, the teacher may need to communicate the meaning in different ways through several modes of learning, and help students to develop the word knowledge necessary to understand the concepts.

This thesis is part of a larger research project, the Budding Science and Literacy project. Central to the larger project was testing and refining a teaching model that integrated inquiry-based science and literacy, the Budding Science teaching model (Fig. 1) (Ødegaard and Frøyland 2009). The initiative was rooted in the Norwegian National Educational Reform of 2006 (Ministry of Education and Research 2006) that integrated basic literacy skills (reading, writing, and talking) in all subjects, including science.

Additionally, inquiry was emphasized in the curriculum to strengthen science education. However, many Norwegian teachers are inexperienced in teaching inquiry-based science, and, especially, the integration of literacy and science (Knain and Kolstø 2011; Ødegaard and Arnesen 2010). Thus, as part of the Budding Science and Literacy project, elementary school teachers were invited to participate in a professional development (PD) course that focused on science/literacy integration as put forward by the Budding Science teaching model. The integrated approach of the teaching model builds largely on Seeds of Science/Roots of Reading (Seeds/Roots), a teaching program developed at Lawrence Hall of Science, Berkeley (Cervetti et al. 2006). Included in this program is systematic and detailed curriculum material, introducing a do it (hands-on), talk it, read it, and write it approach to science teaching and learning. As part of the PD course, the participating teachers adapted and implemented this material in their classrooms. Researchers from the Budding Science and Literacy project videotaped selected teachers as they implemented the material. These video recordings form the basis of the empirical data included in this thesis.

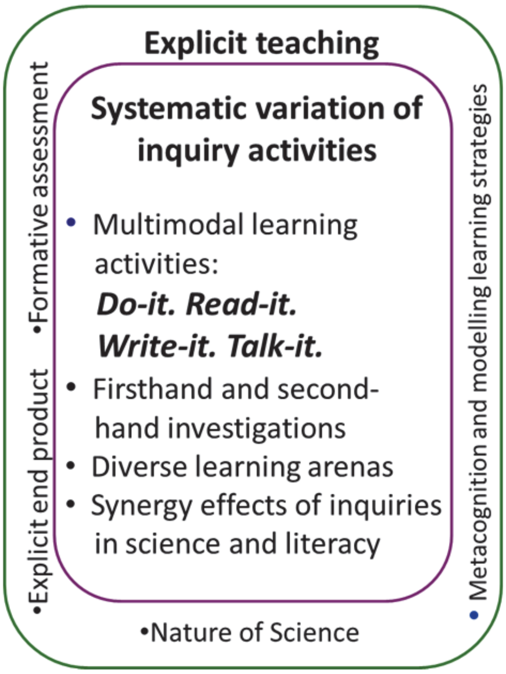

Fig. 1. The Budding Science teaching model. The central educational principles are systematic variation of inquiry activities in science and literacy, combined with explicit teaching. Systematic variation of inquiry activities implies that students use multimodal learning activities (doing, reading, writing, talking), they alternate between firsthand and secondhand investigations, and they use diverse learning arenas. Students take advantage of the synergy effects of inquiry-based science and literacy. Teachers explicitly focus on meta-cognition, modeling learning strategies and formative assessment. The students are systematically reminded of the nature of science context and the end product of inquiry (Ødegaard and Frøyland 2009).

In Norway, extensive research on science education has not been conducted, and the focus thus far has mainly been on secondary education (Kjærnsli, Lie, Olsen, and Roe 2007; Klette et al. 2007). To meet the challenges put forward by low recruitment (Bøe, Henriksen, Lyons, and Schreiner 2011) and low performance on international knowledge tests in science (PISA, TIMMS), what is happening in the early years of science in school must be understood. Thus, this study targeted elementary school and focused on aspects of science education necessary to improve science teaching and learning, including inquiry science.

Despite the prevalence and importance of science inquiry, few research studies have examined teachers' instructional practices in inquiry classrooms (McNeill and Krajcik 2008; Poon, Lee, Tan, and Lim 2012). Large-scale studies show that student learning is enhanced by science inquiry (e.g., Minner et al. 2010), but not how this happens or the teachers' role. Thus, the present small-scale study contributes important information to the field by providing insight into the actual teaching and learning process as it occurs moment-by-moment in the classroom.

1.3 Overarching aim and research questions

The overarching aim of this thesis is:

> *To explore how to teach for conceptual understanding in science within the framework of an integrated inquiry-based science and literacy curriculum.*

This aim is approached through a teaching model (Fig. 1) and related teaching materials. Overall, the thesis intends to reveal areas of instruction that are challenging for teachers, necessitate attention, and require support. Four articles address the overarching aim through separate research questions (Table 1). Each article discusses findings derived from the research questions in terms of implications for improved teaching practice in science. One of the desired outcomes of the four articles is a joint contribution to improving the Budding Science teaching model, which informs teacher education and professional development.

1.3.1 The four articles and their contribution to the overarching aim

The overarching aim of exploring how to teach for conceptual understanding in science is addressed by the four articles in different ways (Table 1 and Fig. 2). Each article has a main aim that is operationalized by the research questions (Table 1) and where the findings are rooted in empirical data and discussed in light of existing literature. Subsequently, the main aim of each article collectively contributes to informing the overarching aim of the thesis as outlined below.

Table 1. The overarching aim of the thesis with an overview of the articles, their main aim, and research questions

Overarching aim of the thesis		
Exploring how to teach for conceptual understanding in science within the framework of an integrated inquiry-based science and literacy curriculum.		
Articles	Main Aim	Research Questions
Article I Challenges and support when teaching science through an integrated inquiry and literacy approach.	*To examine how an integrated science and literacy approach challenges and supports teaching and learning of science.*	*- How do multiple learning modalities vary during an integrated science approach?* *- How are different phases of inquiry distributed throughout an integrated science literacy approach?* *- How are multiple learning modalities and the use of key concepts included in different inquiry phases?*
Article II Formative assessment and teachers' sensitivity to student responses.	*To examine how sensitive teachers are to student responses when teaching for conceptual understanding.*	*- Which features of formative assessment emerge as essential to foster conceptual understanding?* *- How does an integrated science/literacy curriculum provide opportunities for promoting and assessing conceptual knowledge?* *- How can findings from the present study be transformed into a general model for assessment to support learning in science education?*
Article III From words to concepts: Focusing on word knowledge when teaching for conceptual understanding within an inquiry-based science setting.	*To examine how a focus on word knowledge promotes conceptual understanding within an inquiry-based setting.*	*- How does students' word knowledge develop throughout different phases of inquiry?* *- How do teachers facilitate conceptual understanding through inquiry-based activities?*
Article IV Inquiry-based science: Turning teachable moments into learnable moments.	*To examine how teachable moments can be turned into learnable moments within an inquiry-based science.*	*- What is the nature of the teachable moments observed?* *- How do teachers use these teachable moments to support student learning?*

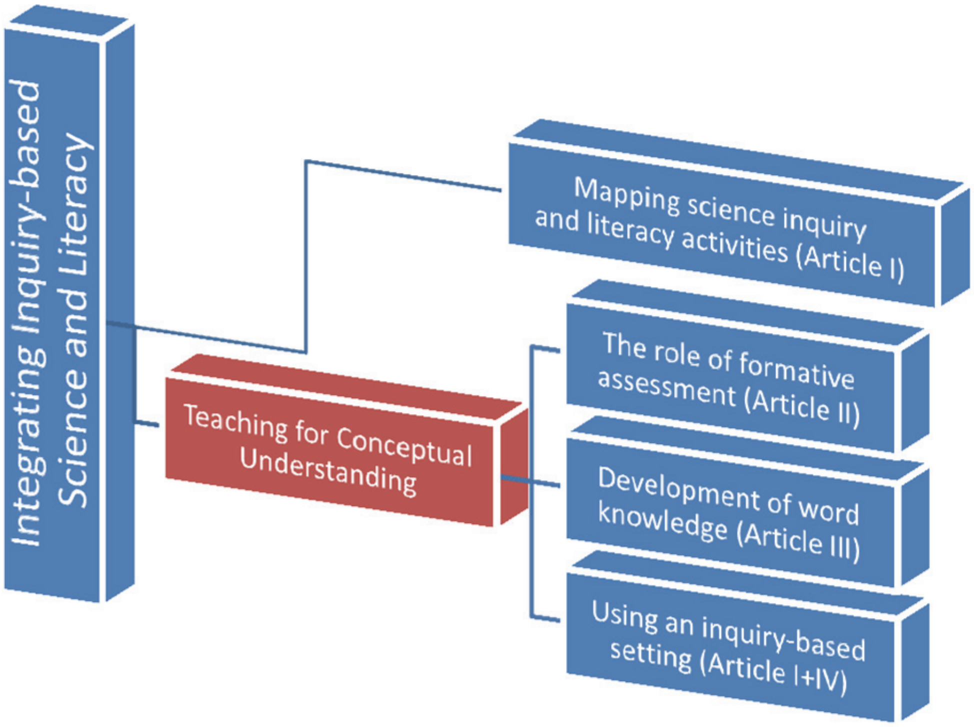

Fig. 2. Diagram of the thesis showing the different articles' contribution to the overarching aim of exploring how to teach for conceptual understanding within a context of science/literacy integration. Article I is an overview study that also forms the basis for the other articles.

Article I is an overview video study of the larger research project (Budding Science and Literacy) and demonstrates the variation and patterns of inquiry-based science and literacy activities in the classroom. Research suggests that consolidation phases, in which students discuss their empirical findings and teachers help students connect their results to theory, are central to conceptual development (Asay and Orgill 2010; Minner et al. 2010). Therefore, Article I contributes important information to the overarching aim by illuminating how much time teachers spend on consolidating students' new knowledge during inquiry. The main aim of this article is to examine how an integrated science and literacy approach challenges and supports teaching and learning science. By studying the occurrence and co-occurrence of literacy and inquiry activities, the patterns may indicate where the challenges are and thus where teachers need support to practice such integration successfully in science teaching. Adding frequency and occurrence of key science concepts to the analysis will provide information on when, and how often, the key concepts important for conceptual understanding are emphasized.

Moreover, this overview study forms the basis for the in-depth studies conducted in the other three articles. The focus in these articles is the classroom dialogue while teaching and learning key science concepts within an inquiry-based setting. The overview coding of inquiry activities and use of key concepts guided my selection of episodes for further investigation. In the second article, development of conceptual knowledge is addressed through features of formative assessment, in the third through development of word knowledge, while the last one stresses the potential for conceptual development offered through an inquiry-based setting (Fig. 2).

In Article II, a model of assessment for promoting conceptual learning is developed. This model builds on theoretical perspectives of formative assessment and empirical data collected through interviews and classroom video of the teachers with reference to their teaching of science concepts. The model is not directly applied in the other articles; however, the model's focus on teachers' sensitivity to student utterances is an important component of the analysis in articles III and IV. Likewise, how teachers respond and act upon students' thoughts and ideas to support students' development of conceptual understanding is central in articles II, III, and IV. Article II contributes to the overarching aim of the thesis by mapping how teachers identify science concepts that are key to understanding the topic being taught, how the teachers elicit students' understanding of these concepts, and the type of feedback the teachers provide to foster conceptual understanding in students. The article's main aim, to examine teachers' sensitivity to student responses, is related to the feedback provided. How teachers interpret the information students reveal during instruction ultimately guides the teachers' further actions, including the type of feedback they provide to scaffold students' development of conceptual knowledge. Feedback is an essential part of formative assessment, and considered by many the most effective aspect of student learning (Bell 2007; Hattie and Timperley 2007; Shavelson et al. 2008). Since teaching for conceptual understanding is at the core of this thesis, the role of feedback, and other aspects of formative assessment, is scrutinized in Article II to examine how teachers use this pedagogical strategy to promote student learning.

The third article's main aim is to examine how focusing on developing students' word knowledge may contribute to fostering conceptual understanding. According to Vygotsky (1987), the development of word meanings and the development of concepts are one and the same process. Bravo et al. (2008) argued that highly developed knowledge of a word is consistent with conceptual knowledge. The present study builds on these theoretical perspectives and contributes information to the overarching aim by identifying different teaching approaches when students are introduced to new science words and concepts through different inquiry activities. In Article I, results from the video coding provide the frequency and occurrence of key science concepts addressed during science inquiry lessons, but not how it is done. The in-depth analyses of teacher–student interaction in this article (III) provide examples of how teachers support and scaffold student understanding within a framework of word development. As in Article II, the teachers' level of support is established based on their responses and reactions to student utterances.

Article IV provides insight from inquiry-based classroom instruction and how this approach can facilitate students' conceptual understanding in science. This article builds on Article I's suggestion that teachers need to spend more time in the consolidating phases of inquiry, letting students discuss and communicate empirical findings in order to develop conceptual knowledge. Article I recommends *what* to do but not *how* to do it. Therefore, this study's contribution to the overarching aim was identifying moments during the discussion and communication phases of inquiry that provide opportunities for enhancing students' conceptual understanding, better known as teachable moments. Furthermore, this article examines how these moments can be turned into learnable moments in which students actually are helped toward conceptual knowledge, the main aim of this article (IV). The study provided examples of teachable moments in which students' utterances were built on or revealed a need for further explanations, and similar to articles II and III, the teachers' responses determined whether the moment was capitalized on and supported student learning.

Seeing how the four articles contribute to shedding light on teaching for conceptual understanding within the framework of an integrated inquiry-based science and literacy curriculum opens up new questions. All articles focus on the teacher and how her actions, including time spent discussing empirical data and responses to student utterances, enable student learning. Overall, the thesis intends to reveal areas of instruction that are challenging for teachers, necessitate attention, and require support. Identifying these areas is only the first step; it is equally important to provide information on and examples of *how* to do it. How to teach inquiry-based science, how to assess for learning, and how to teach an integrated science/literacy curriculum in ways that foster student learning are some of the challenges addressed in this thesis.

2. Overview of previous research and areas for further exploration

In this review chapter, I present an overview of research that has influenced my work. Each of the four articles has its own literature review. Article I in particular has an extensive review of inquiry-based science and literacy integration. In Article II, literature on formative assessment is thoroughly reviewed, while articles III and IV address research on inquiry-based science and conceptual understanding. Thus, these issues will only be touched upon here in order to provide a background for the questions addressed in the thesis. Studies that have come to my knowledge after the articles were written are included and so are some Norwegian studies to help contextualize this research to an international audience. The main purpose of this review section is to place my research within the existing literature, to identify gaps that need attention, and to demonstrate how this thesis will contribute to the field by addressing those gaps.

2.1 Integrating science and literacy

The overarching aim of this thesis is to explore teaching for conceptual understanding in science within the framework of an integrated inquiry-based science and literacy curriculum. A considerable amount of evidence supports the efficacy of an integrated curriculum, in terms of literacy and science outcomes (Cervetti, Barber, Dorph, Pearson, and Goldschmidt 2012; Guthrie, Wigfield, and Perencevich 2004; Hapgood et al. 2004; Pearson et al. 2010; Yore et al. 2004). According to Osborne (2002), literacy is not an additional element to science learning; literacy is as vital to science education as sails are to ships (p. 215). Several large-scale studies have shown that integrated inquiry-based science and literacy activities foster increased learning outcomes when pre- and post-tests were compared with a control class (Cervetti et al. 2012; Wang 2005). A suggested explanation is that when science content is addressed through a combination of inquiry and literacy activities, students learn how to read, write, and talk science simultaneously since these literacy activities support the acquisition of science concepts and inquiry skills (Cervetti et al. 2006; Guthrie et al. 2004; Norris and Phillips 2003). However, these studies were not designed to identify what is actually going on in the classroom during instruction of an integrated science/literacy curriculum, and calls have been made for more in-depth research (Howes, Lim, and Campos 2009; Pearson et al. 2010). The small-scale qualitative studies in this thesis respond to the call for more classroom-based research on science/literacy integration. Article I describes the variation and patterns of inquiry-based science and literacy activities, and how they co-occur, during instruction. Furthermore, articles II and III offer insight into science/literacy classroom instruction focusing on science vocabulary development and how this is linked to conceptual understanding in science.

One of the few qualitative studies that has examined the effect of language and science integration is Glen and Dotger's (2009) classroom study on how three elementary school teachers used language to label and interpret science concepts. Through interviews and classroom observations, the authors analyzed the teachers' use of language as a labeling system and an interpretive system. Language used as labels is fixed, and represents agreed-upon knowledge, mainly used to transmit facts to others. Language used as an interpretive system, however, is described as flexible and a tool for trying out ideas and describing tentative claims about the phenomena (Lemke 1990; Sutton 1996). Interpretive use of language is thus considered crucial in the development of conceptual knowledge in science. Glen and Dotger (2009) emphasized that both types are necessary, since scientific concepts that are well-established can help students explain new claims and allow others to interpret their claims. The authors' findings revealed that teachers used vocabulary to label science phenomena and interpret scientific concepts for students, in which the practice of labeling was used more extensively than interpreting. The purposes of scientific language, however, were not taught. The teachers did not help their students understand why scientists use language in these two ways or how one informs the other. Glen and Dotger's (2009) study pointed at interesting and important aspects of vocabulary learning in science. Still, the authors referred only to how the teachers used the language in science lessons, and not if and how teachers' use enabled students to learn and use the language of science, which is crucial to science learning (Wellington and Osborne 2001). This gap is addressed in Article III in this thesis, in a study that examines how teachers support students' word development toward conceptual understanding and the findings are based on students' use of science words and concepts.

In a Norwegian study on language use in lower secondary (15-year-olds) science classrooms, Kolstø and Knain (2011) found that teachers and students did not use the same type of language. Students used their everyday language, and teachers used the language of science. The teachers did not support or challenge the students to link the two types of languages, and there was no scaffolding of student learning in the use of a scientific language. Without the language, the students were constrained in their learning and unable to link their hands-on activity to the subject matter. The students guessed or expressed that they did not understand what the teacher had explained. Kolstø and Knain (2011) stressed that even if literacy skills in all subjects, including science, are emphasized in the Norwegian curriculum, it was not implemented in the classrooms. More focus on how to integrate science and literacy in the classroom is required through teacher training and professional development. These findings revealed a need for more research and focus on science/literacy integration in Norwegian classrooms. The Budding Science and Literacy project addressed this need and developed a teaching model to help teachers integrate literacy skills in science as required by the national curriculum (Fig. 1, section 1.2). Teachers' implementation of a curriculum based on this model formed the basis for the data collection in this thesis, and the research conducted contributed evidence of teachers' use of the model and suggestions for improvement.

2.2 Science inquiry and conceptual understanding

Several studies have shown that inquiry-based science is more effective in terms of student learning compared to instruction focused on traditional knowledge transmission (e.g., Anderson 2002; Hmelo-Silver et al. 2007; Minner et al. 2010). The participating teachers in this thesis implemented an inquiry-based curriculum, and my aim was to examine their attention to conceptual understanding in students when the teachers enact the curriculum. Thus, the following section concentrates on literature that refers to the impact of science inquiry on student content learning in order to identify gaps that require attention and are addressed in the articles in this thesis.

From mainly concentrating on establishing the effectiveness of inquiry, the field has now moved on to focus more on understanding the dynamics of such teaching and how it can be generated (Anderson 2002). Minner et al. (2010) reviewed 138 studies on science inquiry and observed that inquiry-based instruction had positive effects on students' science conceptual learning. When conducting further analyses, the authors revealed that instruction concentrating on active thinking, such as students engaging with the content by building on prior knowledge, creative thinking, use of logic, and drawing conclusions from data, increased student understanding of science content. Minner et al. (2010) referred to a study by Dalton et al. (1997) and stated that hands-on activities alone were not sufficient for conceptual development. Students also needed an opportunity to process for meaning through class discussion of their observations from the activities. Despite supporting evidence for the importance of grappling with empirical data in order to build conceptual knowledge, Alozie, Moje, and Krajcik (2010) found that classroom discussions were rare and brief in science classrooms.

Most of the evidence of inquiry-based instruction resulting in increased learning outcome for students is based on large-scale test designs in which standardized achievement tests are used to compare the effectiveness of inquiry-based approaches to more traditional instructional settings. The focus of this assessment is often on general constructs labeled inquiry skills, not on specific aspects of the inquiry process, and a precise definition of inquiry skills is usually missing (Crawford 2014). Although the research focus has moved toward understanding how inquiry works in the classroom, there are few examples of how the actual practice is carried out in the everyday classroom. Several studies indicate what inquiry science should include to be successful in terms of fostering conceptual understanding in students but exactly how to do it is not very well examined. Articles III and IV address this scarcity in research by providing practice-oriented examples from inquiry-based science lessons. The examples aim to show how different teaching approaches influence the development of conceptual understanding in students. Furthermore, the importance of students discussing data collected from their own investigations is highlighted in the overview article (Article I), and examples of how to use the discussion phases of inquiry to enhance student learning are presented in Article IV.

Science inquiry is often regarded as an agent for involving students in learning to do science, learning science by doing science, and learning about science (Anderson 2007; Gyllenpalm et al. 2010; Lederman 2006). Even though I believe these aspects of inquiry are intertwined and vital in students' learning and understanding of science, this thesis concentrates on the development of students' conceptual knowledge. Therefore, studies related to content learning within an inquiry-based setting (learning science by doing science) are reviewed here. Several studies have described classrooms in which learning to do what scientists do overrides concerns about content and learning specific scientific concepts. Asay and Orgill (2010) revealed in their review of articles published by teachers that gathering and analyzing evidence were the most prominent features of inquiry-based instruction. The authors suggested that this may be related to teachers viewing inquiry more as a process than as a vehicle for learning science content. In Knain and Kolstø's (2011) research project on inquiry-based science in Norwegian classrooms, they found that the many learning objectives involved when conducting investigations led to an emphasis on one objective on behalf of another. The focus was primarily on hands-on experiments, and only a small proportion of the teachers stressed the subject matter. Similarly, Furtak and Alonzo (2010) reported in their study of elementary and secondary teachers that content did not receive significant attention in the majority of the 28 science classrooms they studied. Teachers prioritized activity over understanding, and they were more concerned with getting students involved in doing and liking science than learning the science content. Furtak and Alonzo (2010) stated that if teachers emphasize knowledge of processes over established science content knowledge, students are unlikely to develop understanding of important science concepts. In another study, Talanquer, Novodvorsky, and Tomanek (2010) examined what prospective science teachers noticed in an inquiry classroom. The authors found that analyzing data and drawing conclusions received far less attention from the participants than students demonstrating general science process skills. When the prospective teachers evaluated the students' presentations, they focused on the completeness of the work and the students' presentational skills, not the quality of the included elements.

Crawford (2007) argued that teachers' conceptions about science may influence how they teach science as inquiry. These conceptions are based on teachers' knowledge of the nature of scientific inquiry (Windschitl 2003). Furtak and Alonzo's (2010) research indicated that new views of science teaching are filtered through teachers' preexisting ideas about how students learn, which are usually based in the teachers' own, traditional learning experiences. These studies add to what Abd-El-Khalick et al. (2004) reported in an international study of inquiry-based science. They argued that regardless of how inquiry has been conceptualized during the past 50 years, research has consistently indicated that what is enacted in the classrooms is not aligned to visions of inquiry presented in reform documents. Moreover, the literature demonstrates the ambiguity of what science inquiry actually means. Many of the reform documents Abd-El-Khalick et al. (2004) referred to describe what inquiry science should lead to in terms of student outcome but not exactly how to do it. Poon, Lee, and Tan (2012) requested more insight into how teachers make certain instructional decisions and more practice-oriented examples. Crawford (2014) agreed, and declared that we lack adequate descriptions of the nature of the classroom inquiry instruction.

In articles III and IV, I address these calls by examining the teaching and learning process as it occurs moment-by-moment in an inquiry-based science classroom. This also involves several examples that illustrate teaching leading to development of students' conceptual understanding. Examples like this are scarce in the literature and are needed. The studies reviewed refer to teachers emphasizing process over content when teaching science inquiry, however; *how* to use the opportunities provided by an inquiry-based setting to promote conceptual understanding in students is seldom addressed. In addition, Article I provides a detailed overview of the variation and succession of science inquiry instruction enacted at the classroom level. Mapping teachers' time spent on different phases of an inquiry cycle helps identify the teachers' choices and gives an impression of the different elements the teachers include, and exclude, in an investigation.

2.3 Formative assessment and conceptual understanding

A central part of teaching for conceptual understanding is dialogue with students to clarify their existing ideas and help them toward scientifically established ideas (Driver, Asoko, Leach, Mortimer, and Scott 1994; Scott, Mortimer, and Ametller 2011). This involves providing feedback to students about how their existing conceptions relate to the scientifically accepted ones and helping students modify their thinking accordingly. Feedback is an essential aspect of formative assessment, and therefore, formative assessment is seen as a crucial component in teaching for conceptual understanding (Bell 2007; Bell and Cowie 2001; Black and William 2009). Thus, teachers' use of formative assessment, and especially feedback, is addressed in Article II.

There is an extensive amount of literature on formative assessment in educational research in general (e.g., Bennett 2011; Black, Harrison, Lee, Marshall, and Wiliam 2003; Black and Wiliam 1998; Hattie and Timperley 2007; Sadler 1989). Within science education, there is also a growing body of research on formative assessment, and it involves seminal work done by well-known scholars (Bell and Cowie 2001; Harlen 2003; Hodgson and Pyle 2010; Shavelson et al. 2008). A number of definitions of the term formative assessment have been proposed over the years; however, what many scholars can agree upon is that for formative assessment to take place the teacher must gather and interpret information about students' thinking and then use this information to help students toward the learning goals (Black and Wiliam 1998; Harlen 2003; Sadler 1989). Based on a number of studies, many researchers consider the feedback part of formative assessment the most effective aspect of student learning (e.g., Bell 2007; Hattie and Timperley 2007; Shavelson et al. 2008).

Lately, criticism has been directed toward research on formative assessment at the classroom level. Coffey et al. (2011) reviewed frequently cited publications—Black et al. (2003), Shavelson et al. (2008), Morrison and Lederman (2003), and Bell and Cowie (2001)—and emphasized the lack of attention to student reasoning described in these studies. Coffey et al. (2011) argued that formative assessment is in danger of becoming a pedagogical strategy without a disciplinary substance, and Bennett (2011) expressed the same concern.

Bennett (2011) published a critical review in which he examined different aspects of formative assessment, including what he identified as the domain dependency issue. He claimed that "to be maximally effective, formative assessment requires the interaction of general principles, strategies and techniques with reasonably deep cognitive-domain understanding" (p. 15). This includes pedagogical content knowledge (PCK) (Shulman 1987), the processes and content knowledge important for proficiency in a domain in addition to knowing how to teach this to students. One implication of this claim is that teachers with a low level of PCK are less likely to know what questions to ask of students, which conceptual difficulties to anticipate, and what actions to take to support the students toward conceptual understanding. Magnusson, Krajcik, and Borko (1999) reminded us that this is especially challenging for elementary school teachers who teach many subjects and typically have less subject matter knowledge than those teaching at higher levels of schooling. Thus, it is no surprise that several studies have reported on elementary school teachers' low level of PCK in science (Appleton 2008; Dixon and Williams 2003; Harlen and Holroyd 1997). A suggestion on how to improve teachers' level of PCK is educative curriculum designed to support teacher learning as well as student learning (Schneider, Krajcik, and Blumenfeld 2005). In a study of four middle school teachers' enactment of an inquiry-based unit, Schneider et al. (2005) showed that when educative features that support PCK were present, the teachers demonstrated appropriate support for students' conceptual learning.

The claim that formative assessment is missing disciplinary substance is further investigated in Article II where teachers' responses to student information are aligned to the scientific idea being taught. As suggested by Schneider et al. (2005), the elementary school teachers who participated in our Budding Science and Literacy research project implemented curriculum materials that provided teacher support, including in-depth science background, instructional strategies, and assessment. How this contributed to teachers' level of PCK, and consequently the impact on student learning, is discussed in

Article II. However, the educative curriculum's influence on teachers' science teaching is a central question present in all four articles.

In Norway, research has revealed an assessment practice consisting of a combination of general praise and the absence of explicit standards that refer to the subject content (Klette 2003; Throndsen, Hopfenbeck, Lie, and Dale 2009). In a report by Hodgson et al. (2010) on behalf of The Norwegian Directorate for Education and Training, teachers were asked to describe their own formative assessment practice. One of the main areas discussed was how teachers monitored students' learning and provided feedback to support their learning. At all levels, there was little evidence of teachers monitoring and following up students' understanding of knowledge, processes, and procedures. The teachers focused on positive feedback (e.g., praise), instruction regarding process, and transmission of content knowledge. The directorate launched a national initiative, Assessment for Learning (2010–2014), to develop teachers' assessment practice. A recent evaluation report of the program showed evidence of improvements; however, there are challenges linked to teachers' level of content knowledge and the fact that teachers have different views of the intention of formative assessment (Sandvik and Buland 2013). Teachers' ambiguous view of the purposes of formative assessment requires attention. More research is needed, and Article II in this thesis helps shed light on Norwegian elementary school teachers' assessment practice and offers recommendations for how this practice can contribute to promoting conceptual understanding.

2.4 Summing up the literature review

To sum up, the literature review was conducted to identify connections between students' conceptual development and teaching strategies involving a focus on science inquiry and formative assessment. A body of literature describes different aspects of inquiry-based science indicating that it increases conceptual understanding, but *how* to do it and *what* inquiry looks like in the classroom has not been very well examined. The results reveal a scarcity of studies reflecting the actual practice carried out in the everyday classroom. Focusing on conceptual learning, this thesis contributes information on teacher decisions in real time during lessons and provides examples of ways to improve practice to enhance student learning.

3. Theoretical perspectives

This chapter concentrates on the basic theoretical perspectives and ideas of learning I drew on when I examined how teachers promote and assess students' conceptual understanding. First, theories of learning are addressed with an emphasis on sociocultural and social constructivist perspectives on teaching and learning. The next sections focus on development of conceptual knowledge through the language used and how science concepts are communicated. It starts with the role of word knowledge before moving on to the importance of language and literacy when teaching for conceptual understanding in science. Since the development of conceptual knowledge in this thesis take place within an inquiry-based setting, the last section (3.5) gives an overview of perspectives on inquiry that have influenced this work.

3.1 Theoretical perspectives on teaching and learning in science

Research and practice in science education are grounded in theories of learning (Sjøberg 2007; Wong 2001), thus, theories of learning need to be considered when examining how to teach for conceptual understanding in this thesis. The emerging question was through what type of theoretical glasses to view the data to make them meaningful and answer my research questions. Theories of learning are often vaguely defined and not always clearly distinguished from each other, and it was not possible, or preferable, to apply one unique theory when collecting, interpreting, and making meaning of the data. The literature showed that just as the theories shape one's interpretation of the data, researchers interpret and shape the theories. Based on their existing beliefs and attitudes, researchers combine and adapt theories in different ways (Sjøberg 2007). This is possible because a learning theory is not a fixed entity depicting a specific point of view. A learning theory consists of several perspectives where aspects of one theory may correspond with aspects of other theories. Thus, instead of placing the work in this thesis within a specific theory of teaching and learning, the thesis is based on different theoretical perspectives I have found useful to use in order to make sense of the data.

Another important issue put forth by Millar (1989) is that a set of principles for learning does not directly translate into a set of recommendations for good teaching. Several scholars agreed with Millar (i.e., Driver et al. 1994; Leach and Scott 2003) but also emphasized that some instructional processes are likely to be more effective than others in supporting learning. Clarke and Erickson (2004) also stressed that universal learning theories that apply equally to all contexts do not exist because of the inherent situated and contextually bound nature of learning.

When examining how teaching can facilitate conceptual development and understanding in the classroom in this thesis, I draw on aspects of well-established theories, mainly social constructivist and sociocultural learning theories. These theories recognize learning as a social activity in which language plays a crucial role in students' active construction of knowledge (Leach and Scott 2003). In the next sections, I provide a brief overview of the ideas and perspectives within the sociocultural and social constructivist theories of learning central to this study and then move on to theoretical viewpoints that address teaching methods that promote conceptual understanding.

3.2 Sociocultural and social constructivist views of learning

Helping students actively construct knowledge by using the language of science in the social environment of the classroom is an important element of my research. This approach is consistent with perspectives within social constructivist and sociocultural views of learning. For the last two decades, the direction of interest within science education research has moved toward how meanings are developed through language and other semiotic means in the classroom (e.g., Carlsen 2007; Lemke 1990; Mortimer and Scott 2003; Sutton 1998; Wellington and Osborne 2001). This signals a shift from an individual view of learning to a view of knowledge construction as a process in which students are being encultured into scientific discourse (Driver et al. 1994). Discourse, a central term in sociocultural learning theory, means that knowledge is arranged in systematic ways of speaking, writing, and thinking (Säljö and Wyndhamn 2002). In a sociocultural perspective, knowledge is discursive, meaning language constitutes an arena where speech gets meaning and limits our perception of the world (Lemke 1990). Furthermore, individuals do not construct meaning on their own, but through different forms of communication and appropriate traditions. The sociocultural perspective of teaching and learning in this thesis involves viewing each student's learning process as a result of social interactions with other students and the teacher, or with cultural products made available to the students in books or through hands-on activities (Leach and Scott 2003).

The research conducted for this thesis aligns with sociocultural viewpoints when it focuses on how the teacher guides the discourse of the classroom and supports the introduction of scientific knowledge and scientific ways of thinking and explaining

(Edwards and Mercer 1987; Mortimer and Scott 2003). The work of Mercer, Mortimer and Scott, and other sociocultural researchers is based on Vygotskian views of learning that emphasize the role of social interaction in the individual's conceptual development. Essential to Vygotsky's perspectives is the idea that development and learning involve a passage from the social context to individual understanding (Vygotsky 1986). The social context may be constituted by a teacher in a classroom of students. Then, students must reorganize and reconstruct the talk and activities of the social plane and make individual sense of what is being communicated (Scott, Asoko, and Lemke 2007). Articles II through IV in this thesis build on this perspective of learning when examining how teachers scaffold students' individual sense making of investigations or talk presented at the classroom level.

Viewing learning as a passage from the social plane of the classroom to the individual student is also dominant within social constructivism. A social constructivist position emphasizes the importance of students as active participants in constructing knowledge. Students cannot be passive recipients of knowledge, and the transfer of ways of talking and thinking about the ideas encountered on the social plane always involves personal sense making. According to Leach and Scott (2003), students cannot construct scientific knowledge for themselves. Thus, the teacher has a crucial role in supporting student learning, which is consistent with Vygotsky's concept of the zone of proximal development (ZPD). Here, students' learning is seen as directly connected to, and dependent upon, the supportive activity of the teacher (or another expert) on the social plane (Hodson and Hodson 1998; Vygotsky 1986). Additionally, for students to make sense of and internalize external knowledge, they need scaffolding (Bruner 1985). When teachers introduce new knowledge, they must provide considerable support to the students and then gradually remove the scaffold part by part until the students become intellectually independent. When teaching approaches that encourage development of conceptual knowledge are studied in this thesis, the type and amount of support provided by teachers are at the core, including teachers' reactions when students reveal their understanding.

Another perspective from social constructivist theory that I draw on in my research is the idea that students' preexisting knowledge influences their learning. This is especially apparent in Article III in which several consecutive lessons from the same classroom are analyzed demonstrating how the teachers address students' existing ideas and their impact on student learning. According to Ausabel, Novak, and Hanesian (1978), the single most important part of learning is what the learners already know, and the teacher needs to map preexisting knowledge and teach according to that. Students come to the classroom with preconceptions about the natural world and how it works, and these ideas are often at odds with accepted scientific explanations (Driver et al. 1994; Leach and Scott 2003; Scott et al. 2007). Previously, the most prominent view of prior conceptions was that they were simply misconceptions. Students' existing conceptions were considered odd and unproductive ideas that required confronting and replacement (Smith, diSessa, and Roschelle 1993). DiSessa (2007) then confronted this view and agreed with Lewis and Kattman (2004) that students' thinking should be seen as "an essential starting point from which scientific understanding can be developed" (p. 202).

These are the basic theoretical perspectives and ideas of learning drawn on in the articles when they examine how teachers introduce key science concepts on the social level of the classroom and how teachers support and enable students to make meaning of the science discourse and internalize new knowledge. The following sections concentrate on how to develop conceptual knowledge in students, with an emphasis on scientific concepts and the language of science.

3.3 Development of conceptual understanding

Science words and concepts and how they are taught and communicated to help students build conceptual knowledge are at the core of this thesis. Science words and concepts are a fundamental part of the discourse of science, and there is robust evidence that understanding the discourse of science plays an important role in learning science (Lemke 1990; Scott et al. 2007; Wellington and Osborne 2001). Throughout their science education, students are continually introduced to new science terms and words. However, the language of science is demanding to teach and to learn, and it is one of the major difficulties in learning science (Driver et al. 1994; Lemke 1990; Mortimer and Scott 2003; Wellington and Osborne 2001). Thus, this thesis's focus on how teachers facilitate students' learning of science concepts is required.

Scientific knowledge tends to be expressed in abstract terms that can be far from everyday ways of talking about the phenomena in question (Haneda and Wells 2010). Everyday concepts are often directly related to the experienced world, while scientific concepts are more abstract and general and relate to other concepts within the specific domain (Wellington and Osborne 2001). When I examine how teachers support students in developing conceptual knowledge through the use of scientific concepts, I build on a framework for word knowledge described by Bravo et al. (2008) (Table 2). Essential to this framework is Vygotsky's idea that "the development of concepts and the development of word meanings are one and the same process" (1987, p.180). From this point of view, language development and conceptual development are inextricably linked; thus, teaching and learning conceptual knowledge begin with decoding words and a basic verbal definition. The framework suggests degrees of word knowledge in which the definitional level is only the start of the students' development of conceptual understanding, not the end. Central to this idea is that knowing a word is not an all-or-nothing phenomenon; it is built up over time. Not until students gain active control of a word, meaning they know how to situate the word in a network of related words and ideas, apply it in relation to their own experiences, and use it in their oral and written communications, do they approach conceptual knowledge (Table 2).

Table 2 Framework for word knowledge. Conceptual knowledge develops alongside an increased understanding of word meaning, indicated by the gradient. Based on Bravo et al. (2008).

	Level of word knowledge	Cognitive process	Explanation
	Low	Recognition	Knowing how the word sounds or looks when it is written.
	Passive	Definition	Being able to recite a word's definition, but having little understanding of the meaning of the word or its implications.
Conceptual knowledge	Active	Relationship	Knowing the word's relationship to other words and concepts.
		Context	Knowing how to use the word in context. Understanding how the word fits into different sentences.
		Application	Knowing how to apply the word in context when engaging in inquiry about the phenomenon being taught. Linking the word to the empirical data.
		Synthesis	Knowing how to use the word when communicating the emerging knowledge about the phenomenon under study. Solving problems in new situations by applying acquired knowledge.

In traditional science instruction, learning new words is sometimes reduced to definitional knowledge of a large number of words (Cervetti et al. 2006). However, the theoretical perspective this thesis builds on considers that knowing the vocabulary of science without understanding how it is used, or why, has little value in the development of conceptual understanding. Although students may be able to define or explain a given concept on a verbal level, the concept remains an abstraction and is not fully understood until it can be applied to specific examples (Howe 1996). This perspective is central to my work and applied in the analysis of how teachers teach key science concepts in articles II through IV.

There are several reasons why I chose to apply the framework for word knowledge (Table 2) instead of the revised version of Bloom's taxonomy, for example (Anderson and Krathwohl 2001). Bloom's taxonomy differentiates the range of cognitive processes subsumed under six major categories: remember, understand, apply, analyze, evaluate, and create. Compared to the framework for word knowledge, Bloom's taxonomy has a linear and fixed hierarchy. Furthermore, Bloom's taxonomy does not take the social and communicative aspects of learning into consideration. According to the present research, and the views on learning included in this thesis, how teaching supports student understandings cannot be explained by focusing upon their mental structure in isolation from the social context in which the learning is meant to occur (Leach and Scott 2003).

Essential to the framework for word knowledge is that words cannot be understood in isolation. They are part of a network of other words, and the understanding of one word in the network depends on prior understanding of other words in the same network (Bravo et al. 2008). Scott et al. (2011) suggested additional links for building conceptual knowledge. This includes making links between everyday and scientific ways of explaining, between scientific explanations and everyday experiences, and between modes of representation. Teaching and learning must involve link-making processes to support students' conceptual understanding. The links must be addressed on the social level of the classroom through teaching, and the teacher must scaffold students in making similar links for themselves. I adopt Scott et al.'s (2011) idea of pedagogical link-making when studying how teachers promote conceptual understanding in students, especially the ways teachers make different types of links available for students and help them make sense and internalize new information through talk at the social level.

3.4 The importance of language of science for conceptual development

An essential aspect of the theoretical perspectives on learning that inform this thesis is the emphasis on language. Language is considered by several researchers the most important mode of communication in science learning (Lemke 1990; Wellington and Osborne 2001), although there are extra-linguistic forms of communication, well put forward by Kress and colleagues (2001). In this section, I address some main considerations of language in science education followed by theoretical perspectives for types of dialogues in the classroom that can contribute to increase conceptual learning.

The debate regarding language and science education goes back several decades. In 1971, Postman and Weingartner argued that almost all of what we normally call knowledge is language, which means that the key to understanding a subject is understanding its language. Biology is not plants and animals; it is language about plants and animals (Postman and Weingartner 1971). Therefore, science teachers are also language teachers. Language, however, is more than a means of constructing science understandings; it is also an end, an essential goal of science literacy (Hand et al. 2003). Even though learning the language of science involves more than mere word learning, word learning is emphasized in Article III in this thesis in which the development of word knowledge is linked to the development of conceptual knowledge. Additionally, word knowledge is considered essential to science understanding since learning the language of science involves using words as labels that allow one to communicate about the ideas and processes of science (Bravo et al. 2008; Lemke 1990).

The sociocultural perspective on science learning in this thesis involves introducing students to the language of science, the concepts, conventions, and ways of thinking and talking that are developed in the scientific community. An established common understanding is essential when explaining something, making an argument, collaborating to solve a problem, or communicating findings. However, there are differences between science carried out in professional settings and school science as enacted in the classroom. School science is defined by a curriculum and focuses on a selection of ideas and ways of thinking, thus constituting a social language in itself. Accordingly, in Bakhtin's (1953) term, learning science involves learning the social language of school science (Leach and Scott 2003). The language used in science, and school science, is more precise and accurate than other social languages, and there is no room for ambiguity. This is different from everyday language in which the same word can have multiple meanings depending on the context, the speaker, and the audience (Bakhtin 1953; Lemke 1990). In science classes, students are asked to talk and think about the world in new and unfamiliar ways, and the connection between the everyday conception of the world and the scientific model of the world can be challenging for students to see. Leach and Scott (2003) recognized the differences between everyday conceptions and school science conceptions as a learning demand. The authors emphasized the importance of identifying the difference and designing teaching to focus on the learning demands. From a sociocultural perspective, learning is a reproduction of preexisting social norms and behaviors (Lemke 2001a). Thus, the everyday conceptions students reveal are not simply personal views but are also often shared views represented by a shared language, which again makes their points of view quite similar (Mortimer and Scott 2003).

3.4.1 Dialogues

Classroom talk and dialogues are an important part of my research, since this is the medium of communication I draw on when analyzing the interaction between teachers and students in the classroom. Central to this work, and as Edwards and Mercer (1987) stated, central to any consideration of how classroom talk promotes learning, is Vygotsky's (1986) belief that language development and conceptual development are inseparably linked. Thought requires language, and language requires thoughts. The teacher gets access to students' understanding through their use of language, for example, students' everyday conceptions, and how the teacher acts upon this information and supports students' development of conceptual understanding is at the core of this thesis. However, several studies have reported that the teacher typically does most of the talking and the explaining in schools (Mercer, Dawes, and Staarman 2009; Wellington and Osborne 2001). The three-part exchange structure known as "triadic dialogue" is most commonly used in classrooms (Lemke 1990). This discourse format typically consists of three moves, initiation (I) (often via a teacher question), student response (R), and teacher evaluation (E), and is commonly referred to as IRE (Mehan 1979). The IRE pattern is often perceived to have restricted effects on students' thinking since the teacher's questions are usually pitched at recall and the students' responses remain brief and framed by the teacher (Chin 2006). Mortimer and Scott (2003) identified a variant of the pattern in which the teacher may give elaborative feedback (F) in the third turn, which encourages a further response from the student, and which can build into a productive dialogue that supports student learning (e.g., IRFRF . . . E). A similar discourse pattern is referred to as reflective tosses (van Zee and Minstrell 1997). The toss metaphor implies that the teacher throws the responsibility for thinking back to a student and all those present in a class by asking a question in response to a prior utterance. Van Zee and Minstrell (1997) suggested that this form of questioning may help teachers shift toward more reflective discourse that helps students clarify their meanings, consider various points of view, and monitor their own thinking.

These perspectives on classroom dialogue are part of the theoretical perspectives in articles II, III, and IV when I examine how teachers facilitate classroom talk and how the type and pattern of the discourse contribute to students' learning. This involves the types of questions the teacher asks, especially what type of dialogues she initiates through the feedback she provides to student responses. Additionally, in this thesis, extra emphasis is put on the science content and its place in the classroom dialogue. For conceptual learning, student reasoning must be aligned to the scientific idea being taught when IRE/IRF pattern or reflective tosses are used.

In Article III, the importance of students practicing to talk science in order to learn science is highlighted. According to Lemke (1990, 2001a), for students to be fluent in the language of school science they need to be given the opportunity to practice the specific language: to speak at greater length, formulate questions, argue, reason, and generalize. Being spoken *to* represents a completely different communicative position than being *involved* in a dialogue and practicing the special discourse traditions in science (Wellington and Osborne 2001). Mortimer and Scott (2003) suggested that individual student learning in the classroom is enhanced through achieving a balance between presenting information and allowing opportunities for exploring ideas. This involves two dimensions: authoritative/dialogic and interactive/non-interactive communication. The first is an alteration between authoritative communication in which the teacher intends to convey information, including factual statements and reviews, and dialogic communication in which the teacher encourages the students to put forward their ideas and explore and debate points of view. The second dimension is between interactive and non-interactive communication. During interactive communication, the teacher and the student contribute; in non-interactive communication, only the teacher speaks. For example, along the continuum of authoritative/dialogic, an interaction is dialogic when more than one point of view is represented and ideas are explored and developed. Talk resulting from the intersections of the two dimensions (e.g., dialogic-interactive, authoritative-non-interactive) is equally important. Mortimer and Scott (2003) believed that the overall quality of classroom talk is determined by the teachers' strategic use of dialogic/authoritative and interactive/non-interactive modes at different phases of a lesson. This communicative approach is applied in Article III to support the interpretation of how the teachers organize the classroom dialogue and how this contributed in terms of enhanced student learning.

3.5 Science inquiry

Inquiry-based science has dominated reform materials in science education worldwide for several decades (Abd-El-Khalick et al. 2004; Anderson 2002; Rocard 2007). The curriculum materials the teachers participating in this study implemented are also based on inquiry. Even though there is confusion about how to characterize what inquiry is and what it means to teach science as inquiry (Crawford 2014), research in general supports the effectiveness of inquiry-based instruction (e.g., Anderson 2002; Hmelo-Silver et al. 2007; Minner et al. 2010). An inquiry-based approach to science instruction includes the pedagogy and the learning outcomes of inquiry. The pedagogy is the method of involving students in designing and carrying out investigations, and the learning outcomes refer to learning science subject matter by engaging in these investigations, in addition to learning about the nature of scientific inquiry (Anderson 2007; Lederman 2006). Scientific inquiry in the classroom is meant to resemble the diverse ways in which scientists study the natural world , and teaching science as inquiry requires more involvement by teachers than traditional teaching (Crawford 2000). When the research group developed a coding scheme for inquiry activities (Appendix A) for the overview coding in Article I, several perspectives on inquiry science were considered. This involved engaging students in a process to make and test hypotheses, plan an investigation, analyze data, make explanations based on evidence derived from investigations, and communicate findings orally or in writing (e.g., Bell, Urhahne, Schanze, and Ploetzner 2010; Cervetti et al. 2006; Crawford 2007; Schwartz, Lederman, and Crawford 2004). In the work with the coding scheme, inquiry was not seen as *a* method or *a set* of activities; inquiry was understood as an iterative process of seeking information where conceptual understanding develops from active construction of knowledge (Schwartz et al. 2004).

Many scholars have acknowledged that robust science learning occurs most effectively through firsthand experience combined with ample opportunities for reflection and rich talk (Bransford, Brown, and Cocking 2000; Metz 2000). Kelly (2014) stressed the reflection part, and stated that knowledge is generated not only from interactions with phenomena (i.e., empirical investigations) but also through epistemic discourse and reasoning around the phenomena. Since concepts are often abstract, invisible, and inaccessible, some scientific concepts may never arise from hands-on experience, no matter how creative or time-consuming that experience may be (Carlsen 2007; Palincsar and Magnusson 2001). Articles III and IV draw on these perspectives when examining opportunities for developing conceptual knowledge within an inquiry-based setting. Furthermore, Palincsar and Magnusson (2001) put forth that data students collect and discuss need not necessarily come from hands-on investigations (firsthand); data students collect by consulting text to learn from others' interpretations (secondhand investigation) are equally important to support learning. This reinforces Dewey's (1938) ideas, as he believed that children learn from activity, through a continuum of their own experience, and from contemplating the writings of others.

To sum up, science inquiry, as applied in this thesis, involves students searching for evidence to support their ideas through firsthand (hands-on) and secondhand (text) investigations. It is equally important for students to engage in critical and logical thinking to learn how to make and revise explanations based on the evidence found. This operational definition ultimately builds on the Seeds/Roots inquiry framework (2009), which makes sense as the teaching material the participating teachers implemented in their classrooms is based on the Seeds/Roots curriculum. This thesis argues that inquiry should not be confused with merely providing students with a series of hands-on activities. Teachers need to engage students in discussing and communicating their findings as these activities are basic constituents of scientific inquiry and essential for the development of students' conceptual understanding. Taking a social constructivist stance, students' understanding of science is actively built in a social setting through a process of debating and negotiating with others (Driver et al. 1994; Vygotsky 1978). Therefore, the classroom discussions and communication of empirical evidence become central when I examine how the teacher enables and supports students' conceptual learning in an inquiry-based setting.

4. Methodological considerations

In this chapter, I describe, explain, and problematize the collection and analyses of the empirical data presented in the four articles. My study is part of a larger research project, the Budding Science and Literacy project, and the chapter starts with an overview that describes the design of the larger project. Then I place my work within the bigger picture and reflect upon positive as well as challenging issues of being part of an established project. For the studies in the four articles included in this thesis, I collected several types of data and applied different types of analyses to inform the overarching aim of how teachers enable students' development of conceptual knowledge. When it comes to data collection and analyses, it is helpful to use various data sources to better understand the phenomena examined and to establish credibility. Methods for data collection and analyses are discussed in separate sections, as well as reflections on the trustworthiness of the design and ethical considerations regarding collecting and using data.

4.1 Context of the study: The Budding Science and Literacy project

The Budding Science and Literacy project is a research and development project aiming to test and refine a teaching model (Fig. 1, section 1.2) that integrates inquiry-based science and literacy, the Budding Science teaching model (Ødegaard and Frøyland 2009). Four people constituted the project group: one professor, one associate professor, and two PhD students. As a member of the research group, my role was primarily to produce evidence-based results the developers could use to improve the teaching model. A basic principle in the Budding Science model is that literacy skills enhance science learning and the context of science enhances literacy skills (Cervetti et al. 2012; Varelas and Pappas 2006). The integrated inquiry-based science and literacy approach of the teaching model builds largely on Seeds of Science/Roots of Reading (Seeds/Roots), a teaching program developed at Lawrence Hall of Science, Berkeley (Cervetti et al. 2006). Seeds/Roots has developed teaching materials that the Budding Science and Literacy project use as support to refine the teaching model. The teaching materials focus on a carefully selected set of key science concepts students learn in depth through a do it, say it, read it, and write it approach to teaching and learning. This means that students the key concepts while they are doing hands-on activities, through classroom discussions, by engaging in textbooks of different genres, and by producing different types of texts (Cervetti et al. 2006).

In the Norwegian Educational reform of 2006 (Ministry of Education and Research 2006), basic literacy skills (reading, writing, and talking) were integrated in all subjects, including science. Additionally, inquiry was emphasized in the curriculum to strengthen science education. However, many Norwegian teachers are inexperienced in teaching inquiry-based science and in integrating literacy and science (Knain and Kolstø 2011). To support in-service teachers enacting the educational reform, the main research project aimed to develop, implement, and improve the Budding Science teaching model in close cooperation with teachers. The intention was to narrow the theory–practice gap by drawing on the teachers' classroom expertise in the development process. The Budding Science and Literacy project therefore invited elementary school teachers to participate in a professional development (PD) course that focused on integrating inquiry-based science and literacy. As part of the PD course, teachers adapted and implemented curriculum materials from Seeds/Roots in the context of their classrooms. The implementation process was video recorded, and these video recordings form the basis of my data collection and analyses. The next two sections provide a further description of the participants, the professional development course, and the implemented teaching material.

4.1.1 Participants and the professional development course

Twenty-two elementary school teachers signed up for the PD course on science/literacy integration. The course generated 10 ECTS credits in science. None of the teachers had any science background; they were generalists who taught all subjects in elementary school (6 to 12 years old). The course lasted for a year (August 2010 to June 2011), and the participants met once a month in the evening after their regular teaching job. We started the course sessions by offering a light meal, followed by informal talk between the members and researchers. This way, the participants got to know each other and the researchers better, and the researchers obtained information on shared difficulties and frustrations among the participants that could be addressed in plenary. We saw that this short break at the beginning of each meeting was beneficial for the learning environment, as described by Borko (2004), and for recruiting participants to our research studies. The rest of the course evening was divided in two: The first part consisted of a talk presented by academic staff and the last part a hands-on investigation guided by the researchers. Topics for the talk varied among pedagogical approaches to reading, writing, and argumentation in inquiry-based science. With the hands-on activities, the teachers were put in the place of a student. They worked in groups trying to find evidence that could help them answer their research questions before presenting and discussing their findings in plenum. This approach is supported in a review study on teacher professional development in science education, in which Capps, Crawford, and Constas (2012) reported that teachers who performed hands-on activities themselves were more successful in terms of student achievement than teachers in PDs who focused on lectures and demonstrations of experiments (e.g., Fogleman, McNeill, and Krajcik 2011).

The typical participant attended the course with one colleague from the same school. The course developers required that two or more teachers from the same school attend the course in order to create opportunities for the participants to cooperate locally. Throughout the year-long PD course, colleagues worked together to implement the Budding Science teaching model by adapting teaching material from Seeds/Roots to the local context of their own classroom (e.g., students' age, time and tools available, teachers' confidence in teaching the subject, school policies). The teachers from the same school created a small community of learners at their own workplace and supported each other in the learning process, just as Borko (2004) recommended in her article on professional development and teacher learning. At the end of the PD course, teachers collaborating at the same school wrote an exam paper together and presented their experiences and reflections related to the implementation process orally to all participants.

Six teachers from the PD course, from four different schools, volunteered to be part of the research study. This involved being videotaped while implementing the teaching material and being interviewed twice, before and after the implementation. Years of teaching experience varied among these six teachers, from the novice who was in her second year of teaching to the experienced ones with more than 20 years of practice (Table 3).

Table 3 Background information for participating teachers.

School	Teacher	Grade (age)	Years of teaching experience	Number of students	ECTS* credits in Science
A	Anna	5 (10–11)	0–5	14	16–30
B	Betsy	1 (6–7)	11–15	18	16–30
B	Birgit	4 (9–10)	11–15	24	16–30
C	Cecilia	3 (8–9)	20+	19	16–30
E	Ellinor	3 (8–9)	11–15	16	31–60**
E	Emma	3 (8–9)	20+	21	16–30

*The generalist teacher training includes between 16 and 30 ECTS credits in science.
Thirty credits are equivalent to a six-month course.
**One extra course in biology

4.1.2 Teaching material

The Seeds/Roots curriculum the participating teachers adapted to their classrooms consists of a number of units covering several topics within the different sciences (life science, physical science, earth science). Each unit consists of 20–40 sessions, and the materials are designed to address important science ideas, offer multiple learning opportunities, and provide appropriate instructional support for students (Cervetti et al. 2006). To help students understand the phenomena taught, a pre-selected set of key science concepts are emphasized throughout the unit. These key concepts consist of words that are central for understanding the scientific idea in each unit, for example, chemical reaction, atom, and molecule in a physical science unit on chemical changes, and function, system, and structure in a life science unit focusing on body systems. Additionally, words that are important to master to conduct scientific inquiry and to understand how knowledge is constructed within science are equally emphasized. These words are present in all units and include, for example, observation, data, evidence, inference, and conclusion. Every unit rests on the principle of science/literacy integration, and the materials are designed to address the pre-selected set of key concepts multiple times through multiple modalities (reading, doing, writing, and talking).

Teachers in the PD course chose among the different units and selected a number of sessions from one unit to teach in their classrooms. Teaching materials for each unit included student textbooks and an investigation notebook, materials for hands-on activities, and a detailed step-by-step teacher's guide. The teacher guides were designed to support teacher learning as well as student learning, and they provided support for elementary school teachers to strengthen their level of pedagogical content knowledge (PCK). This includes an in-depth science background, alternative views commonly held by the students, assessment points embedded throughout the units, and suggestions for how to provide more experience, challenge, and support. The use of such educative teaching materials is supported by research. Schneider et al. (2005) concluded in their study of teachers' use of educative materials that this type of teacher material is necessary to improve science teaching and learning, together with professional development.

4.2 Study design

My research is part of the Budding Science and Literacy project. When I started my work as a PhD student, the project was already running. Thus, the design for the project was established. The central aim of the larger study was to develop a teaching model that integrated inquiry-based science and literacy and to concurrently try out and improve the model in cooperation with elementary school teachers. The curriculum for the PD course had already been set and an open-ended questionnaire to map the teachers' current practice at the beginning of the PD course was created. A prototype for the Budding Science teaching model was designed, and it was decided that the teachers, as part of their professional development, should adapt and implement teaching material from Seeds/Roots. Finally, the bulk of the data to inform the project would be collected through video recordings of this implementation. The design was qualitative in its nature, more interested in depth than width, to understand the teaching and learning processes during science and literacy integration at the classroom level. The role of the researchers during the data collection would be as strictly observers.

Within these boundaries, I was given a large amount of freedom to design my own research study. I wanted to concentrate on the teachers' approach to the pre-selected set of key concepts in the teaching material and how this influenced their teaching. In the pre-planned questionnaire to teachers, I was approved to add an extra question about teaching science concepts (Appendix B). I wanted to collect data on teachers' practice before they started their professional development to use as a reference point when I examined changes in the teachers' practice in Article II. The questionnaire was one source that could contribute data for this purpose. I also wanted the teachers' opinion regarding if and how the teaching material had any influence on their teaching of science concepts; thus, I developed a semi-structured interview guide to use in interviews before and after the implementation (Appendix C). In the first interview, I asked teachers about their existing practices regarding promoting and assessing conceptual understanding in students. In the second interview, I focused on any changes in these practices due to the teaching material. Last, video recordings and observations of the implementation process served as a source for examining teacher–student interactions as they occurred moment-by-moment in an inquiry-based classroom. Video also provided data to support teachers' interviews, and vice versa. Data from the interviews and the video recordings formed the basis of my analysis, while additional sources were used as support. Collection of the different data sources is thoroughly described in the data collection section (4.3) and shown in Table 4.

Being part of an established research project can be positive and challenging. A positive aspect in my case was access to more resources including colleagues who know your study well and with whom you could discuss and draw on their expertise.

Additionally, the voluminous amount of video data collected with multiple cameras in several classrooms would not have been possible singlehandedly. For the generous amount of data to remain a contribution and not a challenge, the data had to be organized in a well-functioning system. I used NVivo 9 (QSR 2012) software to organize my data. A challenge of being part of a larger project is related to decisions already made that are out of one's hands to influence or change. For example, if data have already been collected, one might have to change one's research focus to fit the existing data. Since I became part of the project before the data collection phase, there were no difficulties collecting additional data that were not initially part of the study design (e.g., interviews). An actual challenge was connected to the scheduled data collection. Over a year of my PhD period had passed when the teachers implemented the teaching material in their classrooms and we started to collect video data. This could have caused some time problems for finishing the thesis. However, since classroom research depends on admission to schools and teachers' and students' schedules, this might be more of a general challenge than specifically connected to being part of an established research group.

4.3 Data collection and data sources

Empirical material for the articles in this thesis was collected through multiple qualitative data collection methods (Table 4). Hammersley (1990) and Patton (2002) recommended using multiple methods as a way to enhance the credibility and trustworthiness of research. In Article II, in which the aim was to enrich the understanding of teachers' sensitivity to student responses when teaching scientific concepts, the main data source was individual interviews in which teachers reflected upon their own instructional practice. This was supported by videotaped classroom observations and data collected from the open-ended questionnaire teachers responded to at the beginning of the PD course, reflection notes from the teachers after the PD course, teachers' oral presentations, and written course papers. In addition, I visited each of the six participating classrooms at the beginning of the PD course to observe a typical science lesson and to prepare for the data collection phase. For the other articles (I, III, and IV), data were collected from the video recordings alone. For Article I, video was considered the best method for describing the variation and patterns of inquiry-based science and literacy activities. Articles III and IV aim to provide practice-oriented examples from the classroom, which was best achieved by analyzing the teacher–student interaction as demonstrated in the videotapes.

Table 4 Data collection

	Timeline	Data source	Number of participants	Informing Article
Professional Development	August 2010	Questionnaire	22	II
		Pre-observation visit to the classrooms	6	I–IV
	October 2010	First interview	6	II
	March/April/ May 2011	Video/audio recordings, notes from classroom observations	6	I–IV
		Second interview	6	II
	June 2011	Written paper	22*	II
		Video/audio recordings of oral presentations	22*	II
		Reflection note	22	II

*Participants from the same school wrote the paper and presented together.
There were a total of 11 papers and 11 presentations.

The following subsections provide information on the schedule and strategies for collecting data in this thesis, with an emphasis on video and interviews as the main sources of data.

4.3.1 Pre-observation visit to the classrooms

Before collecting data by videotaping the classrooms, I visited the six participating teachers and observed a typical science lesson. My intentions were multiple: I wanted to visit the schools and see the environment in which the participants worked, talk with the teachers, and observe them teaching an ordinary science lesson before trying out the science/literacy curriculum. Just as important, I wanted the teachers and the students to get a chance to know me better, and to demystify having an observant present.

These visits were also important for planning future data collections. Even though the data from these visits were not collected and analyzed scientifically, they provided information on how to make recordings in the classrooms. Additionally, these visits influenced my research focus, which could be positive and negative. The positive side was that my attention focus was directed toward challenges teachers encountered when they taught science concepts. Using observation to focus the research is described by Barron and Engle (2007). They discussed the importance of good orienting questions to help the researcher maintain a perspective that prevents one from getting lost in the details that video recordings include.

Another impact of these visits became evident later as I realized that my perceptions of the teachers from these first visits heavily influenced how I viewed the collected data. I had to confront these views and be aware of their existence to avoid a biased analysis and interpretation of the data. This type of researcher bias is well-known in qualitative research (Patton 2002). According to Lincoln and Guba (1985), each researcher brings a unique perspective to the study, and it is important to understand the inherent biases and minimize the effects.

4.3.2 Questionnaire

At the beginning of the PD course, all participants responded to a computer-based questionnaire (Appendix B). In addition to providing background information, the teachers were asked to describe their current approaches to reading, writing, and science inquiry, including teaching of science concepts. To inform this thesis, I used the teachers' background information, and for Article II, teachers' responses about teaching of science concepts were used to support the other data sources. The questions were open ended and not intended for statistical use, which would have required a more rigid design (Bryman 2004). Self-report data like these may have many pitfalls, one being social desirability, described by Crowne and Marlow (1960) as a tendency to answer in a socially acceptable way, either consciously or unconsciously. People tend to respond in a way that reflects positively on their own abilities and opinions, or the way they believe the researchers would like them to. Therefore, I did not rely on the self-reported data produced by the questionnaire as my only source of information; instead, I used the responses regarding teaching of conceptual understanding as a supplement to other data sources.

4.3.3 Interviews

The six teachers who volunteered for the research project were interviewed individually twice, the first time during an early part of the professional development course and then again at the end of the course (see Table 4). I developed semi-structured interview guides to obtain information to help answer my initial research questions (Appendix C). At this point, these questions revolved around the teachers' sensitivity to student responses when teaching science concepts, which in the end were explicitly addressed only in Article II. The first interview invited the teachers to reflect upon their daily practice and strategies for teaching scientific concepts in general. The second interview, which was conducted within a few days after the last implementation session, focused on the same, with an emphasis on the Budding Science teaching model and the teaching material applied. The short time span between the last session and the interview ensured that the implementation process was still fresh in the teachers' minds. Since the interviewer was present in the classroom during implementation, episodes of interest could be discussed with common references.

Initially, I planned to conduct the second interview as a video-informed interview by selecting episodes for the teachers to watch and comment upon. This method, known as stimulated recall, generally involves replaying a videotape or audiotape of a teacher's lesson in order to stimulate commentary upon the teacher's thought processes at the time (Lyle 2003). I tried this in two interviews before I rejected the idea, because the teachers tended to focus on their own appearance instead of their interaction with the students. As a substitute, I referred to episodes observed during instruction that I wanted the teachers to comment upon, and since the episodes were recent, the teachers had no problem recalling the episodes without the video clips.

I chose a semi-structured strategy because I wanted the teachers to speak freely but within the topic of teaching and learning science concepts. The semi-structured approach combines a predetermined set of open questions that prompts further discussion and gives the interviewer an opportunity to explore particular themes or responses (Kvale and Brinkmann 2009; Patton 2002). The interview guide served as a tool for navigating the interviews and led the discussion in a direction that informed my initial research questions. Respondents were invited to speak freely, and encouraged to elaborate upon their responses. This required that I, as an interviewer, had to be very attentive to what the teacher said and be ready to pick up and build on information from the interviewee that would be interesting to elucidate. Furthermore, it was important to allow enough time and scope for the teachers to talk about their opinions, and to make them feel comfortable during the interview. In order to avoid teachers feeling anxious and inadequate, I avoided questions that directly critiqued their practice. Instead, I practiced an interview-about-events technique, as suggested by Kvale and Brinkmann (2009). For example, in the second interview I used the teaching material's influence on the teachers' instruction as an entry point for the teachers' responses. I asked the teachers to reflect on ways in which teaching this specific curriculum differed from their previous teaching, if they faced any difficulties, and if they would make any changes either to the curriculum or their own teaching. All the interviews were audio-recorded, and I transcribed them in their entirety. In interviews, as in questionnaires, social desirability (Crowne and Marlowe 1960) might be a bias. This was one reason for choosing to triangulate the data sources to establish credibility, as described in section 4.5.

4.3.4 Video

The classroom implementation of the science/literacy curriculum was video-recorded using several cameras. There were four cameras in each classroom: One small wall-mounted camera faced the students, one camera followed the teacher, and two students wore head-mounted cameras. The wall- and head-mounted cameras had satisfactory audio recordings, while the teacher wore a small microphone linked to the teacher camera. This captured all the teacher talk during the lesson, as well as most of the student talk. Altogether, 35 hours of instructional lessons were video- and audio-recorded, evenly distributed among the six teachers. The majority of the video data for my study was retrieved from the teacher's camera and microphone. This was supported by audio from the students' head-mounted cameras whenever it was necessary to verify statements by students during the whole-class discussions.

For Article I, which is an overview study of the occurrence of science inquiry and literacy activities in the classrooms, we had to video-record all the integrated science/literacy lessons. In addition, for the other articles in this thesis (II–IV), collecting data from more than a single lesson was essential to provide depth and scope to better understand the teaching and learning taking place in the classrooms. Furthermore, with a lengthier stay in each classroom, the camera effect, meaning that teachers and students behave differently in front of a camera, will diminish over time. However, as Derry et al. (2010) stated, it is highly unlikely that teaching can be improved significantly simply by placing a camera in the room. It was also important to keep the classroom environment as authentic as possible and not distract the teachers and students with a lot of equipment. The use of small cameras on the wall did not attract any attention, and the head-mounted cameras caused surprisingly little attention among the students. Before the first lesson, we explained to the students why we were there and that we needed their help for our research. They were also invited to look at and try on the head-mounted cameras to satisfy their curiosity. Since I did not use video from the student cameras in my study, further issues related to those cameras will not be discussed here.

Part of the research involved studying how implementing the curriculum impacted the teachers' ways of teaching; thus, during the classroom observations, the researchers were strictly observers. Being present in the classroom was itself an interference, but apart from that, there were no interference from the researchers' side that could cause problems in determining whether the teachers' behavior was due to their own interpretation of the curriculum or the researchers' interference.

I was present at almost all of the videotaped lessons, and during observations, I took notes of incidents that seemed valuable in terms of teacher–student interaction and learning development. As recommended by Derry et al. (2010) in their seminal piece on conducting video research in the learning sciences, I later used these notes as support when I interviewed the teachers and analyzed the videos. There are several advantages connected to the use of video when analyzing the data material. For example, it enabled very detailed observations as the videos could be played over and over again, also in slow motion when necessary. Video can also enrich other data sources. In Article II, video data supported the interviews to confirm consistency between teachers' saying (interviews) and doing (video). Another advantage of video data is that they are stored in a form that allows new analyses at a later time and by multiple investigators from multiple perspectives (Erickson 2006). As my research progressed, and my understanding of the phenomena examined developed, I revisited the videotapes numerous times with slightly different objectives of what to look for.

4.3.5 Course paper and oral presentation

All the participants in the PD course submitted a written course paper and orally presented their reflections and experiences with the integrated curriculum. Teachers from the same school wrote the paper and presented together. The data retrieved from these sources were mainly used to confirm utterances made in the interviews and applied in Article II. For example, after each oral presentation, there was a question session in which I, when applicable, asked for elaborations or comments regarding topics touched upon in the presentations that were also discussed during the interviews.

4.3.6 Written reflection note

At the end of the PD course, all teachers submitted a short reflection note regarding the teaching material and the course in general. I included the reflection notes as a data source because they were available and I wanted to look for statements regarding teaching of science concepts that could support the other data sources used in Article II. Some of the teachers briefly mentioned the material's focus on key science concepts, which confirmed previous statements in interviews and presentations without adding new information.

4.4 Data analyses

Erickson (2006) reminds us that data sources represent all kinds of information collected for the research purpose, whereas data indicate only the actual information used to support claims or assertions generated from data analysis. Therefore, the first step after collecting data is to select information from the data sources for analysis. The main data source in this thesis was the video recordings that contributed information to all the articles. Additionally, in Article II, other data sources, especially interviews, are also drawn upon (Table 5). The selection of data and analytical methods in the four articles were based on the research questions in each article and guided by the theoretical underpinnings of the thesis. Even though the other sources contributed data only to Article II, teachers' voices from the interviews, written work, and presentations became part of my background knowledge and influenced the way I interpreted the data in all the articles. Drawing on one's own experiences is part of qualitative research, and as Wallace and Louden (1997) stated, qualitative researchers presume that understanding of events is constructed through the presumptions we bring to them.

In the following, I describe how I organized the data corpus, selected data for further analysis, and analyzed the selected data in the different articles (Table 5). I also highlight how the analyses in the four articles jointly contribute to the overarching aim of exploring how to teach for conceptual understanding within an integrated science/literacy approach.

4.4.1 Article I

All the video records were labeled and organized by lessons in separate files for each teacher. For Article I, the four members of the research group coded all recorded video. The aim of this coding was to provide an overview of the science inquiry and literacy activities throughout the lessons. We developed coding schemes before the coding based on theoretical perspectives and existing literature (e.g., Bell et al. 2010; Klette et al. 2007; Schwartz et al. 2004) (Appendix A). There were two coding schemes, one for multimodal activities and one for inquiry activities. The first one was organized according to the principles of multiple learning modalities in the Seeds/Roots material: doing (hands-on), talking, reading, and writing. For the inquiry coding scheme, we needed to create a set of codes that communicated our understanding of inquiry since there are many different opinions of what the term denotes. Our codes were based on an extensive amount of literature (e.g., Barber 2009; Bell et al. 2010; Chinn and Malhotra 2002), and we distinguished between two levels of analysis.

Table 5 Overview of the main aim, data sources, and analyses for each article

<table>
<tr><th colspan="6">Overarching aim of the thesis</th></tr>
<tr><td colspan="6">To explore how to teach for conceptual understanding in science within the framework of an integrated inquiry-based science and literacy curriculum</td></tr>
<tr><th>Article</th><th>Main aim of the articles</th><th>Data sources</th><th>Observed entity</th><th>Unit of analysis</th><th>Framework for analysis</th></tr>
<tr><td>I</td><td>To examine how an integrated science and literacy approach challenges and supports teaching and learning science.</td><td>Video recordings</td><td>Science inquiry and literacy activities</td><td>Classroom</td><td>Integration of inquiry-based science and literacy</td></tr>
<tr><td rowspan="2">II</td><td rowspan="2">To examine how sensitive teachers are to student responses when teaching for conceptual understanding.</td><td>Interviews
Questionnaire
Written paper
Oral presentation
Reflection notes</td><td>Teachers’ utterances</td><td rowspan="2">Teacher</td><td rowspan="2">Formative assessment</td></tr>
<tr><td>Video recordings and written notes from classroom observations</td><td>Teacher–student interaction</td></tr>
<tr><td>III</td><td>To examine how a focus on word knowledge promotes conceptual understanding within an inquiry-based setting.</td><td>Video recordings and written notes from classroom observations</td><td>Student utterances
Teacher–student interaction</td><td>Teacher</td><td>Development of word knowledge
Link-making strategies</td></tr>
<tr><td>IV</td><td>To examine how teachable moments can be turned into learnable moments within inquiry-based science.</td><td>Video recordings</td><td>Teacher–student interaction</td><td>Teacher</td><td>Types of critical moments</td></tr>
</table>

The first level consisted of four categories describing overarching phases of inquiry: preparation, data, discussion, and communication. In turn, each category consisted of several codes that described what we viewed as central inquiry processes. For example, mapping students' prior knowledge and making predictions are two codes in the preparation phase, while discussing different interpretations of collected data is a code in the discussion phase. Additionally, we applied a code named key concepts. This was used when the teaching explicitly focused on the concepts accentuated in the implemented Seeds/Roots material. To get an overview of the classroom activities, we used Interact software (Mangold-International 2010) that allowed us to code the videos directly without transcribing the dialogue. We coded the duration and frequency of each code in order to analyze the occurrence and co-occurrence of the codes. When we started the coding, all four coders collaborated in coding two randomly selected lessons and agreed on when to apply the different codes. Later, we coded individually, and approximately 20% of the videos were double-coded with an interrater reliability of 75–80%, which is satisfactory (Graham, Milanowski, and Miller 2012). The video analysis in Article I differed from that in the other three articles. Article I strictly described the classroom activities, while articles II–IV also tried to explain the phenomena observed by viewing talk between teacher and students through a micro-analytical lens.

4.4.2 Article II

Article II draws on several data sources, of which the interviews form the basis. To organize and handle the sizeable amount of the data collected, we used NVivo 9 software (QSR 2012) to create a database. Organizing the data in a database has several advantages. First, it helped tracking and systematizing data sources, including notes, key documents, transcripts, and video and audio files. Then, these sources were stored in the database for easy retrieval at a later date. Additionally, this made the raw data available for independent inspection if required (Derry et al. 2010; Erickson 2006). NVivo 9 (QSR 2012) was also employed to transcribe and code the interviews and the other data sources for Article II. The transcripts were coded to capture the ways in which teachers described their approaches when promoting and assessing students' conceptual knowledge with a focus on science concepts. For the analyses, we applied a constant comparative method that involved moving back and forth between the sources and codes until there was no more information contributing to the creation of codes (Strauss and Corbin 1994). The codes were grouped into four categories based on theoretical perspectives of formative assessment. The four categories were named Identifying Learning Goals, and Eliciting, Interpreting, and Acting on Student Information.

The main aim of the second article was to examine teachers' sensitivity to student responses when teaching for conceptual understanding. This turned out to be challenging for the teachers to articulate in the interviews and other written data sources. Thus, it was necessary to include the video recordings to search for additional information. Selection of episodes for this purpose was identified based on events discussed in the interviews, notes made during classroom observation, and sequences in the detailed teacher guide where teachers were asked to check for student understanding before moving on with the lesson. In order to examine how teachers responded to student utterances, we looked for episodes involving student talk that revealed the students' understanding of the key science concepts being taught. Then, the teachers' actions were analyzed according to theoretical perspectives of how formative assessment promotes learning (Bell and Cowie 2001; Harlen 2003; Sadler 1989).

Selecting episodes based on supplementary resources is a method recommended by Derry et al. (2010) to reduce the workload of going through countless hours of video. Applying this method might involve missing events that could have added valuable insight to the studies. However, after collecting, organizing, and analyzing the data, I knew the material very well, and I believe that the selection of episodes would not have turned out differently if I had chosen another approach. Erickson (2006) referred to this way of selecting data as a part-to-whole deductive approach. When the researcher has a strong theory and clear research questions, he or she can strategically select video segments from an available corpus to examine those research questions. I also applied this method in articles III and IV, where the teacher guide and overview coding in Article I informed the selection of episodes.

4.4.3 Article III

In Article III, the overview coding from Article I was applied when selecting episodes to inform the study on how key concepts were taught throughout the different phases of inquiry. A co-occurrence analysis of the inquiry phases and the code key concept guided the selection of episodes for further analysis. The aim of this particular study was to examine how the teachers supported students' development of word knowledge toward conceptual knowledge. Students' level of word knowledge was identified based on their utterances and teachers' support was identified in terms of different types of link making and linguistic support. Thus, the episodes selected required a teacher–student interaction where the student expressed his or her understanding orally and the teacher had an opportunity to act upon these responses. The students' level of understanding and how the teacher facilitated conceptual learning was analyzed according to a framework for word knowledge (see Table 2, section 3.3) and various types of link-making strategies (section 3.3). The framework for word knowledge describes different degrees of knowing a word, and highly developed word knowledge is considered equal to conceptual knowledge. Episodes in which the teachers fostered student learning as well as episodes in which the teachers did not were selected to represent the data corpus.

4.4.4 Article IV

For Article IV, I used the teacher guide as support when selecting episodes from the videos to analyze how teachers recognize and use teachable moments. The search for episodes involving potential teachable moments was based on existing literature suggesting that phases of inquiry in which students discuss and reinforce new knowledge are central in the development of students' conceptual understanding (e.g., Minner et al. 2010). Thus, sequences where students were supposed to discuss their empirical findings were first identified in the teacher guide and then in the video material. The first level of analysis on the selection of sequences was to identify teachable moments, defined as occurrences creating opportunities to enhance students' conceptual knowledge. This required student utterances that revealed their understanding or a situation that generated a platform for learning. The next level of analysis was to identify how the teachers used the teachable moments. This analysis was based on Myhill and Warren's (2005) three types of critical moments in which the teachers' response is significant in either supporting or hindering the development of student understanding. The three types of critical moments are i) those that caused confusion for learners, ii) those that steered the discourse along a predetermined path, and iii) those that were responsive to student learning needs (p. 60). To inform the study, I selected several episodes involving teachers using or missing the teachable moments identified.

4.4.5 Articles II–IV's joint contribution to the overarching aim

The analysis in the three articles (II, III, and IV) ultimately aimed to investigate teachers' response to student utterances and how those responses contributed to support students' conceptual understanding. How the episodes were selected for analysis and within which framework and theoretical perspective they were analyzed differed in the three articles (Table 5). In Article II, teachers' descriptions of their teaching of science concepts in the interviews and teacher–student interactions observed in the video formed the basis of the analysis. In this article, teachers' reactions to student utterances were analyzed within a framework of formative assessment. In Article III, episodes were selected based on a co-occurrence analysis of the inquiry phases and the code key concept. The teacher–student interactions observed in the episodes were analyzed within a framework for word knowledge and various types of link-making strategies. This analysis highlighted how teachers supported students' development of word knowledge toward conceptual understanding. In Article IV, I used the teacher guide as support to select episodes to identify teachable moments. How teachers used the moments to promote conceptual understanding were based on teacher–student interaction and analyzed according to three types of critical moments. Viewing the data from different perspectives and using different frameworks for analysis provided a strong foundation for better understanding the teaching of science concepts and development of conceptual knowledge in students.

4.4.6 Focus on language in the analysis

The in-depth analysis of student–teacher interaction in the classroom was based on language as the mode of communication. Talk was chosen as the source when analyzing teachers' reactions to student responses since many consider the spoken language the most important mode of communication in science learning (Lemke 1990; Wellington and Osborne 2001). Even though several researchers emphasize the importance of other forms of communication in science education, for example, gestures (e.g., Kress et al. 2001), learning to talk science is vital for learning science (Lemke 1990; Wellington and Osborne 2001). Furthermore, how teachers scaffold student learning and understanding of science words and concepts are at the heart of this thesis. The focus on language also embraces the science/literacy integration that forms the basis for the entire study. Finally, the emphasis on language in the analysis rests on the learning theories that guide this thesis. This includes viewing learning as a passage from the social to the individual level where the language of science has a crucial role.

4.5 Trustworthiness of the research

Trustworthiness of a research study is important in evaluating its worth. According to Lincoln and Guba (1985), trustworthiness involves establishing credibility, transferability, and dependability. Credibility refers to the confidence in the truth of findings, and can be compared to internal validity in quantitative studies. The concept of credibility focuses on whether the researcher's interpretations are plausible and justified, if sufficient evidence is offered to support the findings (Hammersley 1990; Lincoln and Guba 1985). In this thesis, the many hours spent in the classrooms and the continuing observations provided depth and scope and contributed to build credibility. An even bigger contribution came from triangulation, which is the best-known technique for establishing credibility (Patton 2002). Triangulation involves using multiple methods, theories, and data sources, and different types of triangulation were applied throughout this thesis. Especially in Article II, triangulation of data sources through a combination of interviews, video recordings, and supplementary data sources ensured rich, robust, and comprehensive data. This allowed me to check for consistency and, equally important, inconsistency in the findings. Various analyses were applied to the data retrieved from the interviews and videotapes, which elucidated several aspects of the same phenomena and contributed to enhance the study's credibility. Another example is from Article III in which the overview coding from Article I were used to select episodes for further analysis, thus effectively combining different methods and different analyses to facilitate deeper understanding. For the overall thesis, the overarching aim was investigated through different theoretical perspectives and analytical approaches, resulting in compelling evidence that supported the credibility of the findings.

Lincoln and Guba's (1985) second criterion for trustworthiness is transferability. Transferability involves showing that the findings have applicability in other contexts, thus comparable to the concept of external validity and generalizability. Instead of aiming for random sampling, qualitative researchers are encouraged to provide a detailed portrait of the setting in which the research is conducted**.** The aim here is to give readers enough information for them to judge whether the conclusions drawn are transferable to other situations and settings. One way of achieving this is by describing a phenomenon in sufficient detail, also known as thick descriptions. When writing articles for publication, the format of journals makes it difficult to provide as much contextual information as preferred to meet the criteria of transferability. In this thesis, I have attempted to include adequate descriptions of participants, teaching materials, learning processes, and methods so others can judge the quality of the resulting product, including transferability. Furthermore, generalizability in qualitative research can be achieved with analytical generalization (Kvale and Brinkmann 2009). This implies that the claims raised in the conclusion of a study are based on a combination of the theoretical point of departure, the findings from the empirical analyses, and findings of related studies. In my thesis, I obtained analytical generalization through linking the empirical findings to theoretical perspectives on conceptual development and science/literacy integration and discussing these findings in relation to findings in similar studies and existing literature.

The third criterion for trustworthiness concerns what Lincoln and Guba (1985) referred to as dependability, better known as reliability. Reliability involves judgment about analysis and showing that the findings from which conclusions are drawn are consistent. I made several efforts to strengthen the reliability of the studies in this thesis. One effort concerns the transcriptions of video-recorded teacher–student interactions in the articles (II–IV). Compared to field notes and different forms of recollection of past events, transcripts of video records have a stronger position concerning reliability (Erickson 2006). The detailed descriptions of the analyses of the transcripts help readers follow the researcher's analytical steps along the way. This means that the readers are allowed to reach other conclusions, as well as to question the evidence on which the findings are based. The reliability of the analysis in Article I was strengthened by joint analytical efforts in internal coding workshops for the research group, where sufficient interrater reliability was achieved (Graham et al. 2012).

4.6 Limitations of the study

In this section, I address limitations related to this research. One limitation is that this was the teachers' first time implementing the integrated science/literacy curriculum, and research has linked greater student gains to teachers' increased experience with the curriculum (Fogleman et al. 2011). This may explain some of the teachers' decisions during instruction, and that the teachers occasionally seemed more concerned about the procedure and following the teacher guide than focusing on student learning. Most of the teachers in the study also taught different units to students in different grades. Therefore, it is not possible to directly compare student outcome in terms of content learning. However, all of the units share the same structure and underlying principle of engaging students in inquiry and literacy activities in ways that fosters conceptual knowledge of the science topic being taught, which enabled comparison of teaching approaches.

Another limitation is related to the level of student learning based on the talk of a selection of students representing the entire class. First, interpreting student talk is inevitably subjective, and second, only the students who talk are represented in the analyzed excerpts. There is never a perfect relationship between talking and thinking, and what one student expresses does not necessarily apply to all students in the class. That said, the excerpts were primarily selected to elucidate and represent teachers' actions to further students' learning and not as an indication of what the individual student learned.

Additionally, the reliability of the results is strengthened by providing transparent analyses so readers can follow the line of reasoning (see section 4.5). Some of the same arguments also relate to the interpretation of teachers' action. Since we cannot directly observe what teachers are thinking, our results are based on their actions and responses alone. Therefore, transcripts and detailed descriptions of the analyses were required, for others to scrutinize the interpretation and conclusions drawn. In the studies where video was the only source of data, especially articles III and IV, other data sources such as teachers' comments to the selected episodes could have provided more in-depth understanding of the teachers' moves. However, the research focus changed over time as I watched the videos over and over again. Thus, the initial ideas and research questions I had regarding these articles and how they turned out in the end differed. Refining research questions during research is very common in qualitative research. Wiersma (1986) stated that research questions can be modified along the way, since it is during the investigation the research questions become evident and are clarified, and particular lines of inquiry are taken. Even if it had been possible to revisit the teachers to get their comments on the episodes I finally selected for analysis, by that time it had been more than a year since the recordings. Therefore, I believe the teachers' contribution would have been limited. This is supported by Derry et al. (2010), who pointed out that it is preferable to obtain participant involvement as soon as possible after recording.

Last, according to the theoretical perspectives applied in this thesis, conceptual knowledge develops over time (Bravo et al. 2008). Thus, it would have been preferable to examine teaching and learning over a longer period of time. However, the teachers expressed that they did not normally allocate as much time to each topic as suggested in the Seeds/Roots teaching material, which means that what we video recorded is already an extended version of their daily practice regarding teaching of science concepts.

4.7 Ethical considerations

In the following section, I discuss some of the ethical considerations regarding the research and the presentation and publication of the results. Ethical considerations are important in all types of research, and collecting and using the video recordings required special attention since it is difficult to maintain the participants' anonymity (Derry et al. 2010). According to Norwegian law, and to secure the participants' rights, the research project needed approval from the Norwegian Social Science Data Services (NSD) to videotape teachers and students. The research group submitted an application to NSD that included verification of secure storage of the video files and drafts of letters informing the participants about the research. When the application was approved and before any data had been collected, the information letters were sent to the school principals, teachers, and parents of the minor students (Appendix D). They were also asked to sign an informed consent agreeing to use the video recordings for research purposes. The participants were free to withdraw at any point during the study, and the students had the option of not being videotaped during instruction. None of the participants withdrew or declined to be videotaped.

When we started to record video, we first instructed the teacher how to turn off the microphone she wore, and that she could turn it off whenever she needed to avoid sharing sensitive information. Some teachers used this opportunity when students approached with different types of problems. Additionally, if personal information was video- or audiotaped, this is excluded when the research is communicated and presented. Two students in each classroom wore small head-mounted cameras. Data from these cameras were not included in my study, but as part of the overall research project I was involved in securing the students' comfort and privacy. The students were instructed to call on the teacher or one of the researchers if the students felt uncomfortable wearing the camera, and that they should take it off if they needed to leave the room. During the video-recording, a few students needed help adjusting the camera on their head, and several times we stopped students on their way out who forgot about the camera.

After the data were collected, all video files and other data sources were stored in a secure server that was accessible to the research group only. To ensure participants' anonymity, all names were replaced by pseudonyms during transcription of interviews and video-recordings. Additionally, the name and location of the schools were not used in any of the published material. Since only six teachers participated, the participants could recognize themselves in papers and presentations. Even though the research group discussed the findings with the participants, some conclusions drawn might be considered negative toward the teachers. Therefore, when I am presenting the research, orally or in writing, I always strive to communicate that the studies are not intended as a criticism of the teachers' practice. Rather, the results aim to accentuate aspects of teaching and learning science that require attention, focusing on good teaching instead of viewing what it takes to be a good teacher as a fixed individual asset.

5. Summary of the articles

This chapter provides a summary of the four articles to prepare the readers for the discussion chapter. The first article is an overview study of the larger research project (Budding Science and Literacy) and forms the basis for further in-depth studies. The other three articles are more specifically directed toward teaching for conceptual understanding within a science and literacy integration. In the second article, development of conceptual knowledge is addressed through formative assessment, in the third through development of word knowledge, while the fourth looks at the potential for conceptual development offered through an inquiry-based setting.

5.1 Article I

Ødegaard, M., Haug, B., Mork, S. M., and Sørvik, G. O.
Challenges and support when teaching science through an integrated inquiry and literacy approach. Accepted with major revisions in *International Journal of Science Education.*

5.1.1 Aims, background, and methods

This article provides an overview of the Budding Science and Literacy research project. In this project, researchers worked together with practicing elementary teachers to develop a teaching model that integrates inquiry-based science and literacy. The article describes the variation and patterns of inquiry-based science and literacy activities in six Norwegian elementary science classrooms and how the activities co-occurred during instruction. Inquiry and literacy are important elements of science education. They have a twofold role of affording structures that support science content learning as well as being important areas of content knowledge of the science curriculum (Norris and Phillips 2003; Wellington and Osborne 2001). Several large-scale studies have shown that integrated inquiry-based science and literacy activities provide increased learning outcomes when comparing pre- and post-tests with a control class (Cervetti et al. 2012; Wang 2005). However, these studies do not examine the teaching and learning processes as they occur at the classroom level. Thus, the present small-scale video study aims at describing what happens in the classroom during the implementation of an integrated inquiry-based science and literacy curriculum.

Data material for this study was collected from video-recordings of the curriculum implementation. The videos were coded based on a coding scheme for multimodal learning activities (doing, reading, talking, and writing), and one for different phases of inquiry (preparation, data collection, discussion, and communication) (Appendix A). We coded for frequency of occurrence, correlations, and sequential patterns. In addition, we coded for *concepts*, referring to instruction that explicitly focused on the use of science concepts highlighted in the teaching material. The coding did not explain the phenomena observed but helped us to illuminate and discuss the implications of its occurrence.

5.1.2 Results and discussion

The analysis revealed a variation in the literacy activities. Oral activity was the most frequent activity, partly because it also occurred with the other modalities (doing, writing, and reading). For the inquiry activities, the most striking feature was the large amount of time spent on preparing an investigation (e.g., activating prior knowledge) and collecting data (e.g., doing hands-on activity), while relatively little time was spent on discussions and communication of empirical findings. When we compared the teachers, we saw a considerable variation in the duration of the different inquiry phases. Compared to what was recommended in the teacher's guide, all but one of the teachers spent considerably less time in the discussion phase. The focus on science concepts occurred mainly in the preparation and discussion phases of inquiry.

Our perhaps most interesting results show that, on average, very little time was spent in the discussion and communication phases. This indicates that the students experienced less emphasis on discussing the meaning of their findings. Other studies (Duschl and Gitomer 1997; Furtak and Alonzo 2010) also reported that teachers seem to focus more on tasks, activities, and procedures than on conceptual structures and scientific reasoning. Crawford (2007) stressed that teachers' conceptions of science may influence how they teach science as inquiry. Thus, if teachers see science mostly as an empirical endeavor they might spend less time discussing and communicating results. Our results indicate that the integrated science/literacy curriculum provided support for teaching and learning science. Nevertheless, it was challenging for the teachers to include and use the discussion and communication phases in order to consolidate the students' conceptual learning. The findings suggest that the teaching model must be improved to emphasize the importance of the consolidating phases of inquiry and that the teachers need support to arrange for students to discuss and understand the meaning of their data.

5.2 Article II

Haug, B. and Ødegaard, M.
Formative assessment and teachers' sensitivity to student responses.
Accepted with revisions in *International Journal of Science Education.* (Revised version).

5.2.1 Aims, background, and methods

The focus of this article is how teachers promote conceptual understanding within a framework of formative assessment. More specifically, we identify features of formative assessment that emerge as essential for supporting student learning of science concepts. A vast amount of literature considers formative assessment vital to student learning, and the benefits are largely associated with the positive impact of feedback (Bell and Cowie 2001; Black and Wiliam 1998). For feedback to be effective, however, teachers must act upon the information students reveal during instruction. Thus, when we examined teachers' instructional practices in the present study, our main aim was to explore teachers' sensitivity to student thoughts and ideas. Sensitivity is understood as teachers' ability to notice features in student thinking related to the scientific idea being taught. The formative assessment literature often assumes that teachers know what to look for in student responses; in addition, the importance of teachers being sensitive to information students reveal during instruction is rarely examined or communicated. Thus, this study contributes important information to the field on how teachers' sensitivity to student responses influences teachers' further action and, consequently, student learning.

We followed six elementary school teachers as they implemented an integrated inquiry-based science and literacy curriculum in their classrooms. The curriculum materials were designed to address a pre-selected set of key science concepts multiple times through doing (hands-on), talking, reading, and writing. Data were collected through interviews, before and after curriculum implementation, and video recordings of the implementation. The main data source is the transcripts of the interviews, supported by video to ensure consistency between teachers' saying and doing. Based on the interviews, we created codes using the constant comparative method (Strauss and Corbin 1994) and searched for patterns that could help illuminate the teachers' instructional practice regarding formative assessment.

5.2.2 Results and discussion

Based on our analysis and theoretical perspectives on formative assessment, we constructed four categories: Identifying Learning Goals, Eliciting Student Information, Interpreting Student Information, and Acting on Student Information. In this study, learning goals referred to conceptual understanding of the scientific idea expressed through the key science concepts. When we compared the pre- and post-interviews, we observed how the teachers after teaching the integrated curriculum focused more on key concepts as learning goals. In the next category, Eliciting Student Information, teachers' attention in the pre-interview revolved around their own instruction and what they as teachers were doing, while in the post-interview they focused more on how the students demonstrated their understanding. Furthermore, the teachers described their interpretation of student responses as aligned to the learning goals after the teachers tried out the integrated curriculum. However, video observations revealed that the teachers often taught the key concepts in isolation. Students were asked to recite the definition of single words instead of linking them to other science words and concepts, which is necessary to promote conceptual understanding (Bravo et al. 2008). Regarding the category of acting upon student responses, teachers expressed that they provided feedback mostly in the form of praise, which was confirmed by the video observations.

These findings indicate that it cannot be implicitly assumed that the teachers immediately know the core concept of a scientific idea or how to teach science in ways that fosters conceptual knowledge. One reason might be the teachers' level of science content knowledge and pedagogical knowledge, which several studies have described as typically low for elementary school teachers (e.g., Bell and Cowie 2001; Harlen and Holroyd 1997). Teachers need to have the content knowledge necessary to identify the key concepts of the scientific idea being taught and the pedagogical knowledge required to teach these concepts in ways that fosters conceptual understanding. If not, the teachers will not know what to look for in student responses, nor will they be able to align students' thinking to the learning goals and scaffold further understanding. We considered teachers' identification and interpretation of the learning goals an essential feature of formative assessment, and the importance is often under-communicated in studies on formative assessment. Thus, one implication of our findings is that teacher educators, professional development, curriculum developers, and textbook authors need to support elementary school teachers to identify key concepts within the discipline of science. Equally important is to realize that merely knowing which concepts to teach is not sufficient to promote conceptual learning; instead, the concept must be situated within a network of other words and concepts to make meaning.

5.3 Article III

Haug, B. and Ødegaard, M. From words to concepts: Focusing on word knowledge when teaching for conceptual understanding within an inquiry-based science setting. Accepted for publication in *Research in Science Education.*

5.3.1 Aims, background, and methods

In this article, we explore how two elementary school teachers, Anna and Birgit, supported students in developing deep understanding of science concepts through inquiry-based activities. A growing body of evidence supports inquiry-based instruction as more effective in terms of student learning compared to instruction focusing on knowledge transmission. (e.g., Hmelo-Silver et al. 2007; Minner et al. 2010). However, McNeill and Krajcik (2008) argued that few research studies have addressed the problems that teachers and students face in inquiry classrooms. Thus, observing what inquiry-based instruction actually looks like in the classroom is important, to examine the teachers' instructional practices and the interactions that occur between teachers and students engaged in science inquiry lessons. In this study, science inquiry involves students searching for evidence to support their ideas through firsthand investigations. Additionally, students are engaged in discussions based on the evidence found.

Anna and Birgit implemented an integrated inquiry-based science/literacy curriculum in which students learned key science concepts through developing word knowledge. The connection between word knowledge and conceptual knowledge is accentuated by Cervetti et al. (2006). They advocated that when science words are applied in a context and taught in relation to other science words and concepts, students' conceptual understanding develops alongside their level of word knowledge. Additionally, Scott et al. (2011) emphasized that conceptual learning involves making links between different kinds of knowledge, for example, between students' existing knowledge and new ideas.

We collected data from video-recordings of the curriculum implementation, about five hours in each classroom. The video was coded using a coding scheme that categorized inquiry into four phases: preparation (e.g., activating prior knowledge, making hypotheses, planning an investigation), data (collecting and analyzing empirical material), discussion (discussing empirical data), and communication (presenting findings) (Ødegaard, Mork, Haug, and Sørvik 2012). We analyzed and assessed the students' level of word knowledge in the different phases according to a framework for word knowledge (Bravo et al. 2008). Furthermore, we applied various types of link making strategies when analyzing how teachers supported students' development of word knowledge toward conceptual knowledge.

5.3.2 Results and discussion

The two teachers' way of interacting with students during inquiry activities was quite distinct. In Anna's classroom, the teacher did most of the talking through all the phases of inquiry. When students responded to a question, it was often in the form of short sentences and one-word answers whereas the teacher often took bits and pieces of their responses and turned them into the "correct" phrase. When the students were asked to communicate the results of their investigation, they struggled and did not have the language necessary to explain the process or make arguments to support their conclusion. The students demonstrated a passive level of word knowledge. Birgit, in contrast, required that the students used the science concepts emphasized in the curriculum material throughout all phases of inquiry. She facilitated the use of new and unfamiliar words in new and familiar contexts. The students often discussed the meaning of science words in pairs or groups before the teacher summed up for the entire class. This way, everyone got to talk and express their meanings, not only the students picked out by the teacher. When communicating the results of their investigation, these students demonstrated a level of word knowledge consistent with conceptual knowledge.

Anna's students were not scaffolded linguistically or sufficiently encouraged to talk science, which has been well established as necessary to learn science (Lemke 1990; Wellington and Osborne 2001). Throughout all the inquiry phases, the students remained at a passive level of word knowledge; this observation adds to research stating that inquiry by itself does not foster conceptual understanding (Minner et al. 2010). Our results suggest that students' development of word knowledge toward a level consistent with conceptual knowledge requires that the teacher encourage and scaffold students' use of language throughout the inquiry process. When students master essential vocabulary, they can discuss and communicate their growing understanding of a scientific idea. However, for this to happen, the students themselves must do the talking and make the links between their everyday conceptions and new ideas. This is in line with Lemke's (1990) and Mercer et al.'s (2009) observation that to develop conceptual knowledge, students need to practice the language of science, not just listen to the teacher.

5.4 Article IV

Haug, B. Inquiry-based science: Turning teachable moments into learnable moments. Published in *Journal of Science Teacher Education*

5.4.1 Aims, background, and methods

The main aim of this article was to examine how an inquiry-based approach to teaching and learning creates teachable moments, and equally important, how teachers capitalize upon these moments. A teachable moment provides opportunities to further student learning and involves the time during which learning a particular topic or idea becomes possible or easier (DeWitt 2012; Hyun and Marshall 2003). While teachable moments provide opportunities for learning, learnable moments refer to episodes during which students are actually helped toward conceptual knowledge. Although research supports inquiry-based science instruction as more effective in terms of student learning compared to instruction focusing on knowledge transmission (e.g., Anderson 2002; Hmelo-Silver et al. 2007), research has also shown that actual implementation of science inquiry in school is problematic (Abd-El-Khalick et al. 2004; Ireland, Watters, Brownlee, and Lupton 2012). Thus, this study aimed to provide practice-oriented examples to better understand how teachers can foster student learning during science inquiry.

Data were collected from video-recordings of six elementary school classrooms, 35 hours in total. The participants implemented an integrated science/literacy curriculum in their classrooms by following a detailed step-by-step teacher's guide. This curriculum emphasized learning key science concepts through different phases of science inquiry. The purpose of the video analyses was to identify teachable moments during inquiry and examine how they were capitalized upon to support student conceptual learning. Since several studies have emphasized the importance of consolidation phases for inquiry-based science to be effective in terms of conceptual learning, (e.g., Asay and Orgill 2010; Minner et al. 2010), the first selection criterion was episodes in which students discussed and communicated their empirical findings. From this selection, episodes involving a situation that provided a platform to enhance students' conceptual knowledge were assigned as teachable moments. The talk between the teacher and students and how the teachers acted upon student utterances served as a source for how the moments were used.

5.4.2 Results and discussion

Analysis of the data revealed two qualitatively different ways in which teachable moments occurred: *planned* and *spontaneous.* Planned teachable moments denote phases of inquiry during which the teacher should expect, and be prepared for, student utterances that can be built on or reveal a need for clarification and further explanations. Spontaneously occurring moments were instances when an utterance made by the teacher or a student brought the discourse in a different direction than planned by the teacher. If these utterances created an opportunity to further students' understanding of the topic, the episodes were labeled spontaneous teachable moments. Results suggest that the consolidation phases of inquiry can be considered as planned teachable moments. When students discuss and communicate shared experiences, teachers should anticipate and be prepared to act on students' questions or responses connected to these experiences. There were more planned episodes than spontaneous ones in the data set, which was expected due to the selection criteria for episodes to analyze. Planned teachable moments were predominantly created by the learning activity (discussion) itself and by student utterances or lack of such. Spontaneously occurring events were scarce, but those identified created alternative opportunities for the teachers to follow the pace of the curriculum or adapt to students' needs. Within both categories, there were examples of opportunities capitalized upon as well as missed.

Planned teachable moments in inquiry-based science are, to a certain degree, predictable, while spontaneously occurring ones are not. Findings indicate that scaffolding of student thinking and learning requires that teachers know when the opportunities are likely to occur and how to capitalize upon them as they arise. Thus, as the first step, teachers need to plan for events during which students can discuss shared experiences from the investigations. This means turning away from focusing primarily on the process, and instead, spending more time on sense-making and consolidation as suggested in many studies (e.g., Kang, Orgill, and Crippen 2008; Ruiz-Primo and Furtak 2007). Second, teachers need to know how to capitalize on the planned sequences. Teaching materials can help teachers plan for and facilitate teachable moments, but whether these moments are used to foster conceptual knowledge rests on the teachers' actions. Thus, one implication of this study is that practicing teachers need more support through professional development for how to plan for and effectively use the consolidation phases of inquiry. This includes addressing teachers' pedagogical content knowledge as well as challenging their epistemological beliefs about inquiry-based science and teaching.

6. Discussion and implications

The following chapter starts with a discussion of the main results from the four articles with an emphasis on their collective contribution to the thesis' overarching aim: how to teach for conceptual understanding in science within an integrated inquiry-based science and literacy curriculum. In the next section (6.2), I discuss how these results inform the Budding Science teaching model (see section 1.2, Fig. 1) with a focus on integrating inquiry-based science and literacy through the do it, say it, read it, and write it approach. As part of the Budding Science and Literacy project, one of the purposes of my work was to contribute evidence-based results to refine the Budding Science teaching model and its use in teacher education and professional development. In section 6.3, implications for this thesis are discussed. Finally, in section 6.4, I draw conclusions and make suggestions for future research.

6.1 Aspects to consider when teaching for conceptual understanding in science

A specific contribution of this work to the field of science education is the insight this thesis offers to the actual teaching and learning process as it occurs moment-by-moment in an inquiry-based classroom. This includes aspects of teacher–student interaction that support or impede student development of conceptual knowledge. One of the main findings of this thesis is contributed by the overview of classroom activities in Article I, which revealed that the teachers spent less time in the consolidating phases of inquiry than recommended in the teacher guide they followed. These are phases in which students discuss and communicate shared experiences from their investigations, activities many scholars emphasize are central to students' conceptual development (Asay and Orgill 2010; Kang et al. 2008; Minner et al. 2010). When the teachers actually engaged students in discussing observations from their investigations, the results in Article IV revealed ample opportunities to enhance student learning. However, it depends on the teachers' action whether these opportunities are capitalized on in ways that support student learning. At this point in the inquiry cycle, when students have been introduced to the scientific phenomena through doing, reading, writing, and talking, their need for clarification and further explanations can be revealed through their utterances, or lack of such. Even so, findings based on classroom dialogues in articles II, III, and IV demonstrate that teachers often missed these opportunities to scaffold students' conceptual understanding. One of the intentions of the implemented teaching material was to teach a complete inquiry cycle, including communicating findings and discussing evidence to make and revise explanations. Findings in this thesis indicate that the presence of a discussion phase is not sufficient for all teachers to engage students in developing deeper conceptual knowledge. As Anderson (2007) stated, materials are of major importance, but materials alone cannot do the job.

These first results revealed that teachers need to spend more time in the consolidation phases to create opportunities for supporting students' learning. The next challenge is *how* to capitalize on these opportunities as they arise, in the discussion and communication phases as well as in other phases of the inquiry cycle. Empirical findings in this thesis, supported by the applied theoretical perspectives on learning (Leach and Scott 2003; Lemke 1990; Mercer et al. 2009), suggest that teachers should develop a learning environment focused on the language of science in which students are the main contributors of talk. Two reasons discussed in the articles are elucidated. First, the language of science is considered the mediational means for students' development of conceptual knowledge in science. When new information is made available to students at the social level of the classroom, students discuss and internalize these ideas through the use of language. Second, it is through talk students reveal their current understanding of the scientific phenomenon discussed, and it is through talk teachers can provide necessary support to enhance student learning.

When following two teachers as they implemented the entire inquiry cycle in Article III, results indicated that even though teachers spent time on discussions and student presentations, the quality of the activities determined whether they fostered conceptual understanding in students. This article (III), which focused on the development of word knowledge toward conceptual knowledge, demonstrated that to develop conceptual knowledge, the teacher must encourage and support students' use of language. Students should be the active part doing the talking with the teachers closely scaffolding their learning progress, which involves pushing the students to apply the key science concepts in their talk throughout the entire inquiry process. When students master essential vocabulary, they can discuss and communicate, and subsequently increase their growing understanding of a scientific idea. However, if students have not been properly introduced to the key concepts through the initial inquiry activities, they lack the words necessary to discuss their findings, and the students' development of conceptual knowledge is impeded.

Language is vital to student learning (Wellington and Osborne 2001), and as put forth by Lemke (1990) and Mercer et al. (2009), learning the language of science require practice, not just listening.

The second reason for emphasizing classroom talk is related to a recurrent focus in this thesis: how teachers act upon student responses. Results indicate that student development of conceptual knowledge depends on teachers' sensitivity to student utterances and their subsequent actions. When students are encouraged to do the talking, teachers are provided with information on student understanding. Then, teachers have the opportunity to act upon this information to scaffold student learning, where the typical action is in the form of feedback (Hattie and Timperley 2007). As shown in the study on formative assessment (Article II), the nature of feedback necessary to foster conceptual understanding requires that teachers have knowledge of the key science concepts through which the scientific idea is expressed. This involves knowing how words develop to concepts and how to link different types of knowledge, for example, linking a scientific idea to students' everyday experience, as discussed in Article III. Equally important, scaffolding of student learning through feedback requires attention to student ideas and how their thinking is related to the scientific idea being explored. To guide the students and enhance their learning, teachers need a considerable amount of content knowledge and pedagogical content knowledge (PCK), and scholars often refer to the importance of a sufficient level of PCK for successful science teaching (Appleton 2008; Bell 2000; Harlen and Holroyd 1997).

This thesis has identified challenges teachers encountered in their teaching for conceptual understanding in science within an integrated inquiry-based science and literacy curriculum. Video-recordings in the classrooms revealed that the teachers taught key concepts in isolation, and the nature of the feedback the teachers provided did not primarily address how students' thinking related to the scientific idea being taught. Additionally, when the teachers were doing most of the talking, the students did not develop the necessary vocabulary to guide their conceptual understanding. This, together with teachers devoting more time to preparing and doing hands-on activities compared to the consolidating phases of inquiry, may be related to the teachers' level of content knowledge and/or their epistemological beliefs of science and science teaching and learning. Several scholars argue that elementary school teachers typically have low level of science content knowledge as they are expected to teach a number of subjects and often have limited science background (Ball 2000; Magnusson et al. 1999). Scaffolding of student thinking and learning requires that teachers know when the opportunities for deeper learning are likely to occur, and how to capitalize upon them as they arise. This is not an easy task as it involves understanding content and pedagogy as they come together, which supports Capps et al.'s (2012) statement that teachers need a considerable amount of PCK to teach inquiry-based science. In addition, a vast amount of literature discusses how teachers' beliefs about the nature of science and science teaching influence and shape teachers' interpretation of curricular and instructional approaches (Anderson 2002; Borko and Putnam 1996; Crawford 2007; Lotter, Harwood, and Bonner 2007). If teachers consider science inquiry as primarily hands-on activities and not an arena for developing scientific explanations, the teachers might not understand the importance of the discussion and communication phases.

6.1.1 Teaching for conceptual understanding

The empirical contribution in this thesis highlights the importance of communication with key concepts as the basic structure for developing science knowledge. However, applying well-known communicative approaches (Mortimer and Scott 2003; van Zee and Minstrell 1997) and pedagogical link-making strategies (Scott et al. 2011) in the classroom does not automatically lead to student learning. For these strategies to be successful in terms of student understanding of a scientific phenomenon, students must be the active part responsible for the talking and link making, which again requires language proficiency. Thus, teachers need to scaffold students' vocabulary and word knowledge development necessary to understand the science content, and involve students in activities in which the students can practice the language of science. Furthermore, regardless of the pedagogical strategies applied, the key concepts representing the scientific idea must be at the center of attention to promote conceptual learning and avoid what Coffey et al. (2011) referred to as the missing disciplinary substance of pedagogical strategies. Likewise, stimulating conceptual understanding through science inquiry requires an explicit focus on the key concepts throughout the entire inquiry cycle.

Empirical findings in this thesis suggest that several aspects must be considered simultaneously when teaching for conceptual understanding in science (Fig. 3). Separately, these perspectives have been stressed as essential for teaching and learning science by several researchers: the role of inquiry (Anderson 2007; Minner et al. 2010) language of science (Lemke 1990; Wellington and Osborne 2001), communicative approaches (Mortimer and Scott 2003), and strategies for developing conceptual knowledge (Bravo et al. 2008; Vygotsky 1987). Fig. 3 illustrates the combination of these perspectives as they come together when teaching an integrated inquiry-based science and literacy curriculum. Each perspective represented by a circle contributes partly to the development of students' conceptual understanding; however, it is where the circles meet and overlap conceptual understanding develops.

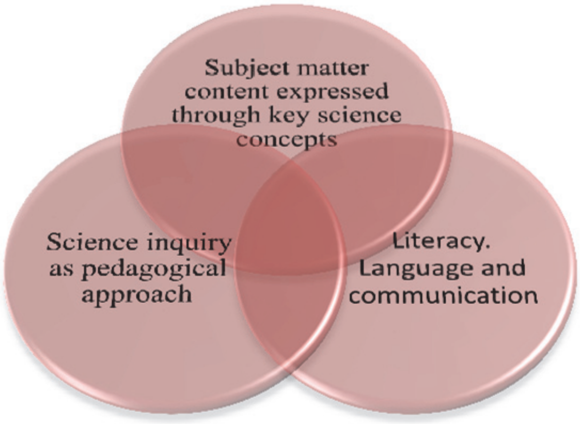

Fig. 3 Combination of essential aspects when teaching for conceptual understanding through an integrated inquiry-based science and literacy approach

6.2 Contribution to the Budding Science teaching model

In this section, I review the contribution of my research to the Budding Science teaching model and the integration of inquiry-based science and literacy (Fig. 1, section 1.2). The following features of the model are addressed in this thesis: explicit teaching through the use of formative assessment and modeling of learning strategies, systematic variation of inquiry activities involving students' use of multimodal learning activities (doing, reading, writing, talking), first- and secondhand investigations, and the synergy effects of inquiry-based science and literacy. Based on the empirical findings in the articles, the importance of focusing on a selection of key science concepts is emphasized and included in the teaching model (Fig. 4). Other contributions are related to reflections on and improvements of the model's existing features involved in this research.

The teacher interviews in Article II showed that the teachers experienced an improvement of their teaching with an increased emphasis on key science concepts. Furthermore, the teachers accentuated how the students demonstrated their understanding through the various learning modes. The pre-selected set of key concepts in the teaching material made the teachers more confident in their teaching as they knew which concepts to focus on to help students learn the subject matter content. In addition, the teachers better knew what to look for when assessing student responses. The teachers expressed that the key concepts provided a direction for the teacher and the students toward conceptual understanding. These statements from the teachers, which emphasized the importance of focusing on few science concepts, led to the inclusion of *few concepts* in the teaching model (Fig. 4).

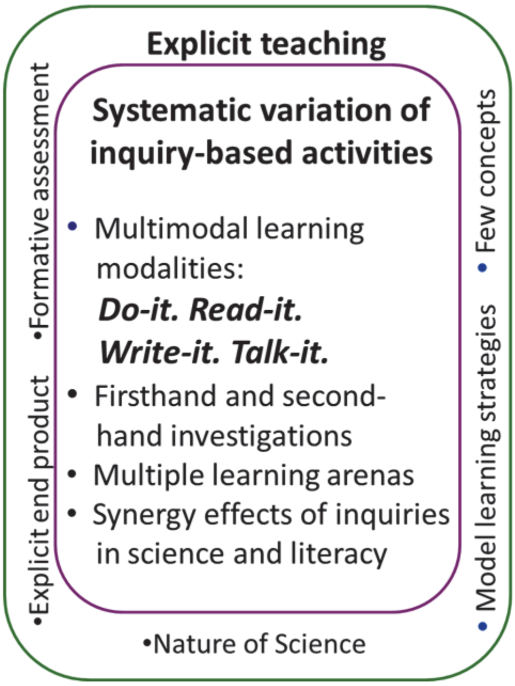

Fig. 4. The refined Budding Science teaching model

How to teach and learn the science concepts is also central to the teaching model. In the interviews, the teachers emphasized how students learned the key concepts by engaging in first- and secondhand investigations and how the do it, talk it, read it, and write it approach enabled teachers to observe and assess student thinking. The teachers' experiences, together with classroom observations, justified and strengthened the decision to include various learning modalities in the original teaching model. Furthermore, the teachers considered the classroom discussions particularly valuable for assessing student understanding, which draws attention to the model's emphasis on explicit teaching through formative assessment. Since the teachers elicited student information through the multimodal learning activities, the teachers gained increased access to student thinking. However, video observations from the classrooms revealed that how to act on the elicited student information in ways that foster conceptual understanding was challenging for the teachers. Feedback that built on student utterances in ways that enhanced development of conceptual knowledge was scarce. The teachers confirmed in the interviews that they usually provided feedback in the form of praise, the type of feedback several scholars regard as least effective for student learning (Black and Wiliam 1998; Butler 1987; Hattie and Timperley 2007). Another observation from the enactment of the teaching model was the lack of explicit modeling of how to apply the key concepts throughout all phases of inquiry. Students were not sufficiently supported in using key vocabulary, and as stressed in the literature, learning the language of science is crucial for learning science (Lemke 1990; Wellington and Osborne 2001). Furthermore, the teachers prioritized activities related to the process of inquiry over activities in which students discussed and tried to make sense of their observations. This requires attention since a growing body of studies have shown that discussing and drawing conclusions based on empirical data are essential for building conceptual knowledge (Alozie et al. 2010; Hmelo-Silver et al. 2007; Minner et al. 2010).

The findings outlined support research suggesting that teaching material is necessary but not sufficient to engage students in developing deeper conceptual knowledge (Anderson 2007). Even though the Budding Science teaching model always was always intended as a supplement to teacher education and professional development (Ødegaard and Frøyland 2009), results indicate that the participating teachers did not receive sufficient support to use the model's full potential. Pre- and in-service teachers implementing the model need substantial support to teach according to the model's principles and in ways that fosters conceptual understanding in students.

The Budding Science teaching model reflects aspects that are critical for successful teaching and learning of science, and the research conducted in this thesis supports the importance of the existing features in the model. However, to support science instruction the model must be operationalized clearly and decisively so that the different aspects are understood in relation to each other. When teachers teach for conceptual understanding, as examined in this research, key science concepts are a common denominator linking different features of the model. The key concepts are central to the development of conceptual knowledge and students meet these concepts multiple times through hands-on and literacy activities throughout all inquiry phases. Thus, when teachers assess student understanding and model learning strategies, development of students' use and knowledge of the key concepts should guide the teachers' actions.

6.3 Implications

When exploring how to teach for conceptual understanding in science in this thesis, some of the challenges encountered for the teachers were as follows: how to teach inquiry-based science, how to assess for learning, and how to integrate science and literacy in ways that foster student learning. Out of this, further questions emerged, including the following: how to provide necessary support for successful teaching and what kind of support is necessary for teachers to overcome these challenges? In addition, who is responsible for providing such support to teachers when introducing new reforms that involve new ways of thinking about teaching and learning for the teachers?

In the articles in this thesis, the main focus is on the teachers and what they should do to promote student learning. However, successful teaching is not the individual teacher's responsibility alone. According to a sociocultural perspective, a person's actions are shaped by the social and cultural context in which the actions take place (Säljö and Wyndhamn 2002). Lemke (2001b) built on this as he reminds us that to make sense of what is going on at one level, we always need to look at least one organizational level below the level we are interested in and one level above. For example, it is essential to consider classroom dynamics in relation to individual activities and in relation to broader school contexts. Thus, the school as an institution has a responsibility to contribute by offering adequate resources in the form of time, equipment, and participation in professional development. Furthermore, when policy makers introduce new educational reforms, money must be granted to professional development courses that can educate the teachers and prepare them to teach according to the reform's principles. This involves extra resources to develop PD programs, teacher education institutions, and the school owners.

Another question involves how to provide necessary support for successful teaching, and what kind of support is necessary. Findings in this thesis indicate that teaching material alone is not sufficient. Therefore, the PD program must be revised and refined to provide sufficient support to improve science teaching and learning. A challenge in education research is to establish a direct relationship between teacher learning and student learning (Blank, de las Alas, and Smith 2008). Increased teacher learning through PD does not automatically foster increased student learning. In a review of inquiry-based science PD programs, Capps et al. (2012) suggested that several aspects must be considered simultaneously to assess the effectiveness of the PD course. None of the studies Capps and colleagues reviewed linked enhanced teacher knowledge (subject matter knowledge, knowledge of nature of science and inquiry) to changes in teacher beliefs, actual classroom practice, and enhanced student learning. The majority of the articles focused on only one or two outcomes, predominantly enhanced teacher knowledge. According to Capps et al. (2012), this is not sufficient if increased student achievement is the desired outcome. Even though teachers' level of content knowledge and pedagogical knowledge are central for successful science teaching, content and pedagogy must come together, and teacher knowledge must be closely linked to development of student understanding. As demonstrated in this thesis, student learning will not be enhanced if the teachers put pedagogical practices such as formative assessment and inquiry to work without explicitly knowing why, how, or what they are supposed to accomplish. Furthermore, a considerable amount of research has suggested what effective teaching should include, but examples of how teachers should do this are lacking (Crawford 2014). One implication from the empirical results in this thesis is that teachers need more practical examples of *how* to teach the science/literacy curriculum in ways that enhance student learning, not only information on *what* makes it effective. Thus, when we introduce the Budding Science teaching model to pre- and in-service teachers in ongoing and future PD courses, we will emphasize several aspects of science teaching and learning. In addition to stressing the role of the key science concepts, we will provide and discuss examples of how to build on student utterances, how to scaffold students' conceptual understanding, and how to apply the key concepts in discussions based on student observations. Moreover, teachers' epistemological beliefs about science teaching and learning will be constantly challenged, which is an aspect beyond the scope of this thesis.

6.4 Final remarks and next steps

In this thesis, I explored how to teach for conceptual understanding in science with an emphasis on scaffolding students' understanding of science concepts. An integration of inquiry-based science and literacy formed the context of the four articles, and I examined science teaching from different perspectives. The results contribute to the growing understanding of how to teach inquiry-based science in ways that fosters conceptual understanding, why the language of science is crucial to science learning, and how the integration of science and literacy support student learning.

My research focused primarily on the teacher, and further research is required to understand the effects on student learning. This includes examining how students apply the key concepts when they work in groups during different inquiry activities. In addition, exploring how teacher interference connected to students' group activities influences student learning is important. Furthermore, the results of the research in this thesis helped refine the Budding Science teaching model. New PD courses now use the refined version of the model. How teachers implement this version and whether it promotes conceptual understanding require more research. Last, follow-up studies on how professional development influences teachers' classroom practice in science over time are lacking (Capps et al. 2012). Thus, revisiting the participating teachers in my study and observing their teaching today would contribute important information to teacher education and PD courses.

In conclusion, the findings in this thesis demonstrate that there is still work to be done in the area of teaching for conceptual understanding in science. However, I believe the contribution made in the following articles is a step in the right direction.

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FARGET SIDE

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ARTICLE I

Challenges and support when teaching science through an integrated inquiry and literacy approach

Marianne Ødegaard, Berit Haug, Sonja Mork, and Gard Ove Sørvik

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Abstract

In the Budding Science and Literacy project we explore how working with an integrated inquiry-based science and literacy approach may challenge and support the teaching and learning of science at the classroom level. By studying the interrelationship between multiple learning modalities (read it, write it, talk it, do it) and phases of inquiry (preparation, data, discussion, communication), we wish to illuminate possible dynamics between science inquiry and literacy in an integrated approach. Six teachers and their students were recruited from a professional development course to the current classroom study. We video recorded the teachers as they implemented an integrated inquiry-based science and literacy teaching model in their classrooms. This paper presents an overall video analysis of our material demonstrating variations and patterns of inquiry-based science and literacy activities. Our analysis reveals that the multiple learning modalities are all employed in the integrated approach, with a prominence of oral activities. The inquiry phases shift throughout the students' investigations, but the consolidating phases in which students discuss and communicate their empirical findings are given less space. The multiple learning modalities are integrated in all inquiry phases, but to a greater extent in the preparation and data phases. Our results indicate that activities embedded in science inquiry provide support for teaching and learning science, however, the greatest challenge for teachers is to find time and courage to utilize the discussion phase to consolidate student learning.

Keywords: inquiry-based science, literacy, video-analysis, multiple learning modalities

Introduction

Inquiry and literacy are both important elements of science education. We want to explore how an integrated inquiry-based science and literacy approach may challenge and support the teaching and learning of science in six Norwegian primary school classrooms. Our understanding of inquiry is concurrent with Crawford's (in press) definition: "teaching science as inquiry involves engaging students in using critical thinking skills, that includes asking questions, designing and carrying out investigations, interpreting data as evidence, creating arguments, building models, and communicating findings, in the pursuit of deepening their understanding by using logic and evidence about the natural world". We consider literacy necessary to engage in science inquiry and acknowledge that literacy, both in the fundamental and derived senses (Norris and Phillips 2003), are crucial parts of scientific literacy. The fundamental sense is based on the essential role of text in science and involves reading and writing and being fluid in the discourse patterns and communication systems of science. The derived sense is derived from the fundamental sense and involves being knowledgeable and educated in science and being able to take a critical stance on information.

Inquiry and literacy have a twofold role of affording structures that support science content learning as well as being important areas of content knowledge of the science curriculum (Knain and Kolstø 2011; Norris and Phillips 2003; Wellington and Osborne 2001). Pearson Moje, and Greenleaf (2010) claim that science and literacy are each in the service of the other, and that a curriculum based on the two will give synergy effects. Science learning benefits from embedded literacy activities, as literacy learning benefits from being embedded within science inquiry. However, there have been calls for more research in order to understand the challenges teachers encounter in the classroom when using science literacy integration (e.g. Howes, Lim, and Campos 2009). Accordingly, there is also a need for research on how teachers' practice can be supported to successfully implement integration of inquiry-based science teaching and literacy (Hand et al. 2003; Howes et al. 2009; Pearson et al. 2010). In this article we address two main research questions:

1) What challenges do primary school teachers encounter in classrooms when adopting an integrated inquiry-based science and literacy approach?

2) What conclusions can be drawn from such results regarding the support teachers may need to integrate such an approach more successfully?

The questions are investigated through video based observations of six primary school classrooms.

Norwegian Context

In Norway, there were two prominent changes in the national curriculum reform of 2006 (Ministry of Education and Research 2006). First, inquiry was accentuated in grades 1-11 through the introduction of a main subject area on inquiry (named the Budding Scientist) which focused on the processes and nature of science. Second, a new cross-curricular demand for integrating subject literacies, denoted as basic skills in all subjects: i.e. reading, writing, arithmetic, oral and digital competence. Hence, the Norwegian national science curriculum facilitates for synergy effects between science inquiry and literacy. However, research conducted on the curriculum implementation concluded that the demand to focus on basic skills does not seem to be understood and thus not perceived as meaningful by teachers (Møller, Prøitz, and Aasen 2009; Ottesen and Møller 2010). The researchers claimed that the curriculum reform has not led to notable changes at the school level. Based on this research, the Ministry of Education and Research (Ministry of Education and Research 2006/2013) has now revised the national curriculum to emphasize literacy as an aspect of scientific inquiry (Mork 2013).

Motivated by the national curriculum reform in 2006, we developed a teaching model, Budding Science and Literacy (Ødegaard, Frøyland, and Mork 2009) inspired by the Seeds of Science/Roots of Reading (Seeds/Roots) teaching program (Barber 2007). Similar to the Seeds/Roots program, Budding Science and Literacy focuses on systematic use of multiple learning modalities (reading, writing, talking, and doing) when enacting inquiry-based science. As part of the curriculum development, primary school teachers were invited to participate in a professional development course focusing on inquiry-based science and literacy. With our support, the participating teachers tried out and adapted teaching materials from the Seeds/Roots units in their own science classrooms. Six teachers from the professional development course volunteered for the present research project.

Research on Science Literacy Integration

Over the past 20 years, a research agenda has emerged in science education and literacy research communities to integrate language and literacy instruction in the context of science inquiry (Hand et al. 2003; Pearson et al. 2010; Yore et al. 2004). The longstanding research program Concept-Oriented Reading Instruction (CORI) was one of the first research initiatives to promote reading engagement through content-area learning in grades 3 and 5 (e.g. Guthrie et al. 1996; Guthrie, Wigfield, and Perencevich 2004). The CORI framework emphasized the role of science and science inquiry as a setting to provide students with forms of interaction with a topic that facilitates reading (Barbosa and Alexander 2004). Results from small-scale CORI studies showed positive outcomes for science concept learning, reading comprehension, reading strategy use, and reading motivation (Guthrie et al. 2004). Palincsar and Magnusson (2001) developed the Guided Inquiry Supporting Multiple Literacies (GIsML) research program. In this program, two forms of investigations were combined to support teachers' and students' participation in science inquiry: firsthand investigations (hands-on) and secondhand investigation (consulting text to learn from others' interpretations). The researchers designed "the scientist's notebook" genre, which models a scientist interpreting data and making inferences based on evidence, inviting students to engage in the interpretation along with the scientist in the text. In a quasi-experimental study, Palincsar and Magnusson (2001) found that students with notebook-based instruction learned more than the comparison group with more traditional text. Classroom observations further showed that the classroom talk reflected the inquiry process when the text was used. More recently, Cervetti, Barber, Dorph, Pearson, and Goldschmidt (2012) investigated the effects of an integrated science literacy approach compared to content-comparable science-only teaching. The science literacy approach employed stems from the Seeds/Roots teaching program which has inspired the development of the teaching model used in our study. 94 fourth-grade teachers participated in Cervetti et al.'s (2012) study, and they found that the students in the integrated science literacy group made significantly greater gains in science understanding, science vocabulary, and science writing.

The studies described above, together with several other studies on science and literacy integration, showed increased gains in student learning in both science and literacy (e.g., Fang and Wei 2010; Romance and Vitale 2012). A suggested explanation is that when science content is addressed through a combination of inquiry and literacy activities, students learn how to read, write, and talk science simultaneously as these literacy activities support the acquisition of science concepts and inquiry skills (Cervetti, Pearson, Bravo, and Barber 2006; Cervetti et al. 2012; Hand et al. 2003; Norris and Phillips 2003). However, few studies have examined how the science and literacy integration actually looks like in the classroom. Howes et al. (2009) conducted a classroom study in which they provided detailed descriptions of how three primary school teachers linked science and literacy. They found that in some cases literacy learning was favored over science learning. This led the researchers to conclude that not all forms of integration equally support students' engagement in science inquiry. In light of these findings, Howes et al. (2009) called for further research "to understand more clearly what challenges teachers' encounter in employing science–literacy integration and how we can support teachers to practice such integration successfully in their inquiry science teaching" (p.214).

The present study aims to answer this call by mapping time spent on reading, writing, talking and hands-on activities throughout different phases of inquiry in six primary school classrooms. This will contribute information on the variation and patterns of multiple learning modalities and phases of inquiry and help illuminate areas of instruction where the science literacy integration is challenging for teachers and requires support.

Theoretical Background

In the following, we present theoretical perspectives on science inquiry and language and literacy in science central to our analyses. Our analytical framework presented in the Methods section builds on these perspectives.

Science Inquiry

Many national reform efforts and policy documents worldwide stress that inquiry should be a guiding principle for science education (Abd-El-Khalick et al. 2004; Millar and Osborne 1998; Ministry of Education and Research 2006; National Research Council 1996; Rocard et al. 2007). Calls for students to engage in science inquiry can be traced back to John Dewey (1910), who advocated science learning through extended experiences with authentic problems. Also a recent review of research trends in science education from review of research trends in science education from 2003-2012 (Lin, Lin, and Tsai 2013), indicates that scientific inquiry has become the influential research concentration of science education researchers.

An understanding of scientific inquiry and the nature of science is regarded fundamental to the development of scientific knowledge. In the literature, three uses of inquiry in classrooms are usually described: a) a set of skills to be learned by students, b) an understanding of the processes of science, and c) a pedagogical strategy where students learn science by doing science (Gyllenpalm, Wickman, and Holmgren 2009; Lederman

2006). There is no consensus regarding how inquiry is related to science teaching and learning. The difficulties in defining inquiry science, have led to debate on the merits of inquiry-based science education (Anderson 2007; Hmelo-Silver, Duncan, and Chinn 2007; Kirschner, Sweller, and Clark 2006). At times, inquiry science has been grouped with problem-based learning and discovery learning as minimally guided instructional approaches. However, there is strong agreement that the role of the teacher in teaching science as inquiry is central to support students in making sense of data and scaffold their personal understandings of scientific knowledge (Crawford 2000). In the present study, we map the time spent in different phases of inquiry and we examine teacher involvement based on how the instruction was organized. Science inquiry implies that students search for evidence to support their ideas and engage in critical and logical thinking (Barber 2009).

Science inquiry is often described as a "multifaceted activity" (National Research Council 1996) that involves posing questions (Chinn and Malhotra 2002), exploring (Bybee et al. 2006), testing hypotheses (Gyllenpalm and Wickman 2011), designing and carrying out investigations (Crawford in press), analyzing data (Krajcik et al. 1998), making explanations based on evidence (Barber 2009), and debating and communicating findings (Wu and Hsieh 2006). Bell, Urhahne, Schanze and Ploetzner (2010) emphasized that these processes do not appear in a fixed order and should not be interpreted as steps in a linear fashion. A number of studies focus on one or two features of science inquiry (Furtak, Seidel, Iverson, and Briggs 2012). We wanted to examine the entire inquiry process at the classroom level, and we rely on several of the features listed above in our analytical framework.

Language and Literacy in Science

Increased interest in socio-cultural perspectives on teaching and learning has emphasized language as the central form of mediational means in science learning (Leach and Scott 2003; Lemke 1990). Thus, the emphasis on learning the language of science is vital for student learning, both as a structure that support science content learning as well as an area of content knowledge of the science curriculum (Knain and Kolstø 2011; Norris and Phillips 2003; Wellington and Osborne 2001). Additionally, as Wellington and Osborne (2001) stated: "for many pupils the greatest obstacle in learning science—and also the most important achievement—is to learn its language" (p.3). Learning the language of science involves more than mere word learning, yet word knowledge is essential to science understanding as learning the language of science involves using words as labels that allow one to communicate about the ideas and processes of science (Bravo, Cervetti, Hiebert, and Pearson 2008; Lemke 1990; Wellington and Osborne 2001). Norris and Phillips (2003) argued that science would not be possible without text and our socially meaningful ways of dealing with these texts. Further, they defined scientific literacy as including the fundamental sense and the derived sense of scientific literacy. The fundamental sense involves reading and writing and being fluid in the discourse patterns and communication systems of science, while the derived sense involves being knowledgeable and educated in science and being able to take a critical stance toward information. In our study, when we map time spent on reading, writing and oral activities the focus is mainly on the fundamental sense of scientific literacy. However, when identifying the variation and patterns of literacy activities in different phases of inquiry, it implies that the content of the talk, the reading and the writing is closely linked to understanding the processes of science and mastering the science content. Thus, the study also comprises the derived sense of scientific literacy.

Despite the focus on inquiry in science reforms, and the understanding of literacy in science as central to what it means to do science, texts have usually not been considered sources to support experiences acquired in hands-on science (Norris and Phillips 2003; Pearson et al. 2010). According to Cervetti et al. (2006), a text can provide a meaningful context for investigations and extend the inquiry by being closely connected to the hands-on activities. Literacy is at the core of scientific conduct and it is through language and text that scientific knowledge develops. The activities of constructing, interpreting, selecting, and critiquing texts are as much a part of science as are collecting, interpreting, and challenging data (Norris et al. 2008). Therefore, when the students in our study engage with science texts, they do more than simply recognizing words and locating information.

Methods

Context

The present study was part of a larger project; *The Budding Science and Literacy project*, where the aim was to provide teaching materials to scaffold teachers when implementing inquiry and basic skills in science. The project was inspired by the Seeds of Science Roots of Reading program (Barber et al, 2007) and we developed a teaching model integrating inquiry-based science and literacy adapted to the Norwegian school culture (Ødegaard et al. 2009). We also developed a professional development (PD) course for primary school teachers. The course focused on teaching science according to the teaching model, with lectures on e.g., inquiry, reading and writing in science, combined with practical activities. In addition, the teachers were required to adapt and try out a Seeds/Roots unit[1] in their own classroom.

The Seeds/Roots units consisted of a detailed teacher guide, several short textbooks for students written in different genres, student investigation notebooks and materials for hands-on activities. The units covered a range of topics (e.g. body systems; designing mixtures; gravity and magnetism; variation and adaptation) adjusted to grades 2 through 5 using the "Do it, Talk it, Read it, Write it" approach. By using the teacher guide the teachers were urged to expose students to these multiple learning modalities while learning central concepts (e.g. *system*, *structure*, and *function* in the "Body systems" unit, and *observation*, *evidence* and *inference* included in all units). Concurrently, the students practiced their skills in reading, writing, and discussing in an inquiry-based setting. The teachers were free to choose the unit that was most appropriate for their science class (topic and age level). Although the teachers were encouraged to follow the teacher guide closely, it was not a requirement.

Participants

Six teachers from the PD course volunteered for the present video study (Table 1). They came from four different schools, and their students ranged from age six through eleven. The six teachers were selected based on practical reasons; scheduled lesson plans and accessibility of schools. Ellinor and Emma were selected because they were at the same school, doing the same unit in two parallel 3rd grade classes. All teachers were generalists, teaching all subjects and with little formal education in science. They were video recorded during a sequence of five to ten science lessons per teacher, depending on how much time the teachers could allocate according to their classroom schedule. The video-taped lessons were in consecutive order.

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[1] http://scienceandliteracy.org/about

Table 1. Overview of background information of participating teachers, schools and recordings

Teacher	Years of teaching	Science Credits*	Grade	No of students	School location	Theme	Total video rec. (in min.)
Anna	0–5	16–30	5	14	S	Gravity & magnetism	343
Betsy	11–15	16–30	1	18	R	Body systems	165
Birgit	11–15	16–30	4	24	R	Body systems	426
Cecilia	20+	16–30	3	19	S	Variation & adaption	540
Ellinor	11–15	31–60	3	16	R	Designing mixtures	224
Emma	20+	16–30	3	21	R	Designing mixtures	269
					(Suburban Rural)		Σ 1967

*Generalist teacher education includes 16–30 ECTS credits in science (60 credits is one year full time study).

Data Material

In the present study, rich and robust data (e.g., several parallel videos from the same lesson) allowed us to enhance the trustworthiness of the video observations (Derry et al. 2010). The data material from each class consisted of *observational data* which included video recordings of whole-class settings, video and audio recordings of the teacher, video and audio recordings from two head-mounted cameras worn by students, and classroom audio recordings. Additionally, the Seeds/Roots teacher guides were used as *reference data* with its detailed descriptions of the different activities, including suggested time spent on each activity.

Development of Coding Schemes

The aim of this study was to identify challenges primary school teachers encounter in their classrooms during the inquiry science and literacy integration, and the support the teachers might need through the integration approach. To recognize the challenges, we needed to look for typical features of inquiry-based situations in science classrooms. Therefore, we developed a coding scheme for science inquiry that was based on an extensive review of literature and recent research into inquiry-based science education, the nature of science, and current models of inquiry cycles or frameworks, e.g., 5E (Bybee et al. 2006) and the Seeds/Roots inquiry cycle (Barber 2009). The coding scheme was developed in an iterative process between reflecting on theory and watching video examples of classroom activities. We distinguished between two levels of analysis consisting of four overarching phases of inquiry (categories): preparation; data; discussion; and communication, which again were operationalized by what we have identified as central inquiry processes (specific codes) (Table 2). We concur with the argument made by Bell and colleagues (2010) that science inquiry in school science classrooms does not have to take form in a fixed order, nor does it have to "fulfill" every process to be classified as inquiry-based. As part of the preparation phase (Bell et al. 2010; Chinn and Malhotra 2002; Gyllenpalm and Wickman 2011; Knain and Kolstø 2011; Osborne et al. 2003), we identified background knowledge, wondering, formulating researchable questions, making predictions and hypotheses, and planning. Specific codes of the data phase (Bell et al. 2010; Krajcik et al. 1998) are collecting data, registering data, and analyzing data. For the discussion phase (Bell et al. 2010; Duschl and Osborne 2002), the following codes were included: discussing different interpretations, views and ideas, making inferences, discussing implications, and linking theory and empirical data. Finally, as part of the communication phase (Bell et al. 2010) we identified oral communication of results, written communication of results, and evaluation.

To get an overview of how the multiple modalities were integrated in the different phases of inquiry, we developed an additional coding scheme for reading, writing, oral, and practical activities (Table 2). These activities correspond with the multimodal activities "Read it! Write it! Talk it! Do it!" in the Seeds/Roots units (Cervetti et al. 2006). We included codes for the instructional organization to examine the degree of teacher involvements throughout the lessons. These codes were inspired by the PISA+ study (Klette et al. 2005; Ødegaard and Klette 2012). See Table 2.

The code *key concept* was used when the teaching focus was explicit on learning topic specific vocabulary (e.g., system, function, and structure) or inquiry specific vocabulary (e.g., observation, predict, and evidence). The Budding Science and Literacy teaching model accentuated learning of a set of pre-selected key concepts, important for understanding the scientific idea being taught. We consider explicit teaching of science and inquiry vocabulary as vital for students' conceptual learning (Haug and Ødegaard 2014). Hence, a focus on key concepts can be considered an important support structure, and the lack of focus can be considered a challenge.

Table 2. Coding scheme for video analysis (Ødegaard, Mork, Haug, and Sørvik 2012). The inquiry categories are labeled after inquiry phases, and the multiple learning modalities are from the Seeds/Roots (Cervetti et al. 2006).

	Category	Specific codes
Inquiry	Preparation	background knowledge/wondering/researchable questions/prediction/hypothesis/planning
	Data	collection/registration/analysis
	Discussion	discussing interpretations/inferences/ implications/connecting theory and practice
	Communication	orally/in writing/assessing their work
Multiple learning modalities	Oral activities	whole class/group/pair/individual
	Writing activities	whole class/group/pair/individual
	Reading activities	whole class/group/pair/individual
	Practical activities	whole class/group/pair/individual
	Focus on key concepts	

Data Analysis

To identify the teachers' challenges and reveal areas that required support when teaching an integrated science inquiry and literacy curriculum, we searched for patterns of activity of the described coding schemes by analyzing the following aspects:

a) The variation of multiple learning modalities during an integrated science approach, whether they are evenly distributed or some modalities dominate.

b) The distribution of different phases of inquiry throughout an integrated science literacy approach.

c) The inclusion of multiple learning modalities and the focus on key concepts in different inquiry phases.

Data analyses were conducted with Interact coding software.[2] We first coded all the classroom videos for multiple learning modalities and instructional organization. The categories of oral, writing, reading and practical activities were not mutual exclusive, but the organizational codes for each of the categories were mutual exclusive. This means that an incident could be coded as both an oral and a reading activity, but whether it was conducted in plenary, as a group or individually could be assigned only one code. The

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[2] http://www.mangold-international.com/software/interact/what-is-interact.html

next layer of coding was the inquiry codes. We applied mutual exclusive codes for the inquiry phases as well as for the specific codes of each phase. The third layer of coding focused on key concepts. We coded the occurrence and duration of each code, and investigated co-occurrence of codes within the different layers.

To get an overview of the classroom activities we used software that allowed us to code the videos directly without transcribing the dialogue (Mangold-International 2010). When we started the coding, all four coders (authors) collaborated in the coding of two randomly selected lessons and reached agreement on when to apply the different codes. Later, we coded individually and approximately 20% of the videos were double-coded. The interrater reliability varied between kappa values of 0,75 and 0,80, which is satisfactory according to Banerjee, Capozzoli, McSweeney and Sinha (1999).

Even though this is a qualitative study, we have chosen at this stage to quantify our results. This opens up for additional patterns of classroom activity to emerge from the data (Ødegaard and Arnesen 2010). In the present study, we do not aim to explain the phenomenon we observe, but to illuminate and discuss the implication of its occurrence. Further in-depth studies based on our results might come closer to explanations.

Results

Multiple Learning Modalities

The analyses show variation in the learning modalities. Summing up all analyzed videotaped lessons, oral activity was the most dominant modality in terms of the time spent, which is not surprising since it naturally occurs together with the other modalities (Table 3). The variation in the modalities largely agreed with the modalities recommended in the teacher guide in the Seeds/Roots material. The teacher guide provided a detailed teaching plan with recommended use of time on each learning activity. However, when each teacher was studied, individual discrepancies were identified, indicating that the teachers made individual adjustments to the advised plans in the teacher guide. This implies that teachers made room for variation even though the teacher guide provided a specified plan.

Table 3. Variation of learning modalities. Summary of video analyses

		Plenary	Group/pair	Individual	Σ
Oral activity	(Talk it)	54%	8%	0.50%	62.50%
Writing activity	(Write it)	6%	3%	20%	29%
Reading activity	(Read it)	6%	3%	0%	9%
Practical activity	(Do it)	4%	8%	1%	13%
Σ		70%	22%	21.10%	

When examining how the different activities were organized (Table 3), we saw that practical activities were mostly conducted in group or pair settings, often combined with oral activity. Plenary practical activities were few and when we checked each incident, they were usually demonstrations by the teacher or students. Writing had the highest percentage of individual activity, although some writing activities were conducted in plenary, either for modeling or as part of an oral activity. Only 9% of the time coded for multiple learning modalities was coded as reading. Most of the reading activities in our video recordings were plenary and intertwined with oral activities. To make the coding as reliable as possible we decided to strictly code the actual reading. However, we have a broad perspective on reading, including getting ready to read, modeling reading, etc., which will be further explored in another study.

To sum up from coding of the learning modalities we saw that oral activities in plenary were the far most dominating. The oral activities co-occurred with the plenary reading, writing and practical activities. When investigating further, we saw that these plenary sessions were often used to model reading, writing and hands-on activities for the students. This indicates that teachers supported the students' activities by modeling in plenary before the students tried out the activities on their own.

Inquiry Phases

We analyzed the inquiry activities according to the codes in Table 2. In the overview of all coded materials in Figure 1, the most striking feature was that the teachers spent a large amount of time in the preparation and data phases of inquiry and relatively less time in the discussion and communication phases. The time allocated to the different activities does not in itself reveal information about the quality of the activity. Practical activities will necessarily take more time than discussions. However, this pattern seems to agree with previous studies showing how school science mostly concerns preparing and doing, with less focus on summing up activities (Ødegaard and Arnesen 2010), debating (Newton, Driver, and Osborne 1999), making inferences and connecting theory and empirical data (e.g., Furtak and Alonzo 2010; Ødegaard and Arnesen 2010).

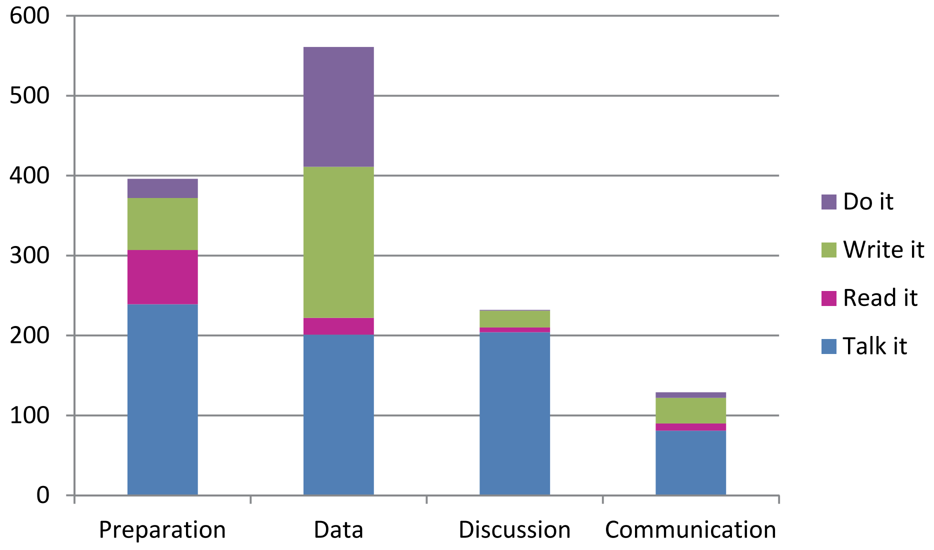

Figure 1. Variation of the multiple learning modalities during the inquiry phases summarized for all teachers and displayed in coded minutes.

The specific inquiry codes for each inquiry phase (see Table2) were mainly used to determine in which phase the coded incident belonged to. Additionally, we wanted to label incidents to make our data material searchable for further research. The specific codes were connected to activities recommended in the teacher guides. The overall picture of the six teachers revealed that the most frequent activities in the preparation phase were activating students' prior knowledge and wondering. When we coded for the data phase, it was difficult to differentiate between collecting, analyzing, and registering data. Therefore, these codes overlap with an emphasis on collecting and registering. In the discussion phase, discussing interpretations and connecting theory and empirical data were most frequently coded for. Making inferences and discussing implications occurred more seldom. When students communicated their inquiry findings, this was mainly an oral activity but also conducted in writing. The students assessed their own work and their peers' work for almost one fifth of the communication phase. We applied the code *Focusing on key concepts* in about 11% of all coded time. This code is independent and thus overlaps with several other codes.

This quantitative summary of six teachers' inquiry activities in school science gave us an indication of how much time the students were engaged in the different inquiry phases. If the students are less engaged in the discussion and communication phases than the preparation and data phases, this might indicate a significant challenge for the teachers. The understanding of science concepts is made deeper and richer through discussing different interpretations, making connections between own data and theory, and making inferences. Therefore it is important to use time on these activities (Haug and Ødegaard 2014).

Analyses of lesson sequences using inquiry features showed progression with preparation first, work with data and often alternation between discussion and communicating results. Occasionally, a small inquiry, for example using a text for collecting and discussing data was used as preparation for a more extensive investigation. When examining the time each teacher spent on the inquiry phases (see Figure 2), we saw considerable variation. Birgit's profile stands out from the other teachers in the study considering time spent on discussion and communication phases. Anna also used considerable time on discussions. Even though Cecilia, in line with Betsy, Ellinor, and Emma, spent most of the time on preparation and data activities, she also had a pronounced communication phase.

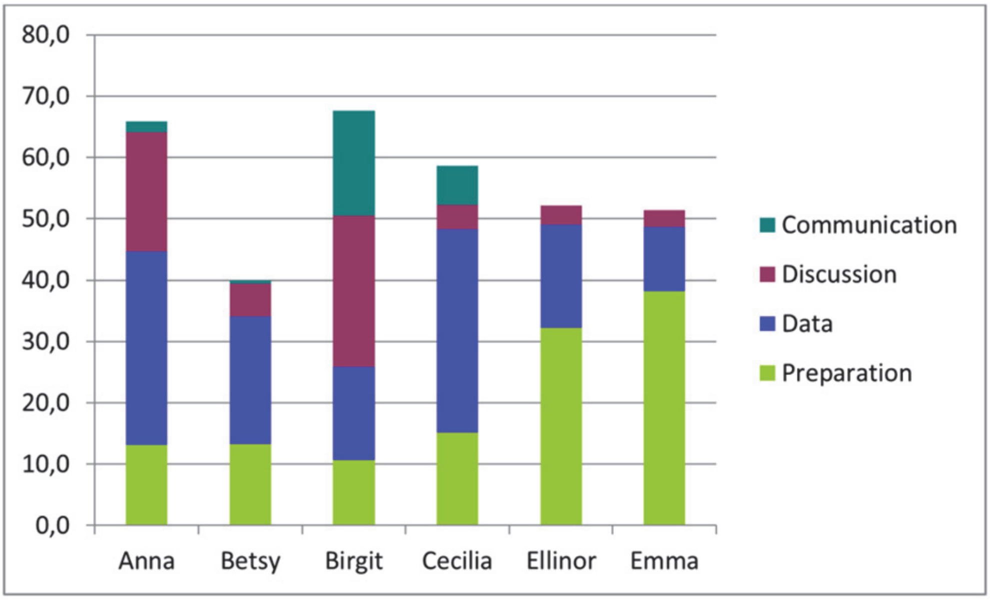

Figure 2. Durations of the inquiry phases for the six teachers in percent of coded time.

Use of Teacher Guide

The teachers chose different Seeds/Roots units (see Table 1). Still, all units rest on the same principles of integrating inquiry-based science and literacy through the do it, read it, write it, and talk it approach, which made the comparison of teachers valuable in terms of teaching an integrated curriculum. To understand more about the challenges teachers meet when implementing this teaching approach, we compared the amount of time the teachers spent on different learning activities to what was recommended in the teacher guides (Figure 3). Each lesson in the teacher guide had a recommended time schedule for the different learning activities. The activities were grouped according to inquiry phases, allowing for analyses that illuminated the teachers' emphasis on the different phases.

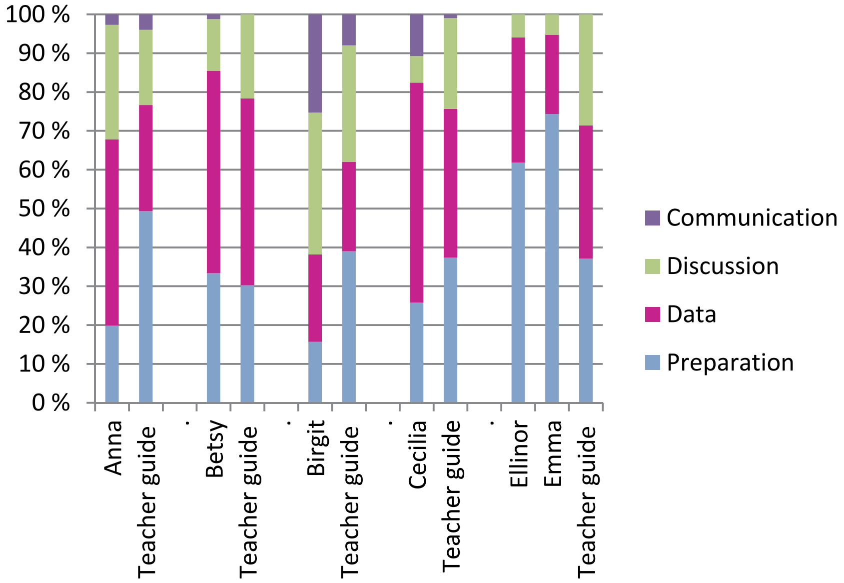

Figure 3. Comparison of inquiry phases between teachers' implementation and the teacher guide. To compare the teachers' implementation with the teacher guide, the duration of the inquiry phases was converted to 100%.

When we compared the teachers in our study with the activity schemes in the teacher guides, it was possible to perceive the discrepancy between what the teachers were encouraged to do and how they actually implemented the learning activities. However, all the teachers used more time on each session than recommended so in order to compare the emphasis on the different inquiry phases the results are shown in percent of coded time. Figure 3 illustrates the amount of time each teacher and her students spent on the inquiry activities in the different phases, compared to the recommendations of the teacher guide. We saw that four of the six teachers spent less time in the discussion phase than suggested.

Ellinor and Emma, who taught the same grade at the same school and followed the same teacher guide, interpreted and implemented the learning activities slightly differently, but both reduced the discussion phase. There was little emphasis on the communication phase in the teacher guides for the lessons observed, thus, the information from this phase of inquiry is limited in this study.

Multiple Learning Modalities in the Inquiry Phases

One of the fundamental ideas of the Budding Science and Literacy project is the synergy effects of integrating inquiry-based science and literacy. Pearson and colleagues (2010) expressed it like this: "Science learning entails and benefits from embedded literacy activities… literacy learning entails and benefits from being embedded within science inquiry" (p. 461). As mentioned, research has also shown how literacy activities can provide structure to inquiry processes (Knain and Kolstø 2011). Therefore, it was crucial to explore the connections between the inquiry codes and the multiple learning modality codes which were coded independently in two different layers of coding. When we combined the inquiry coding and the multiple learning modalities, we saw for instance that data were collected and handled using the entire range of modalities (Figure 1). Data might be collected when doing practical activities, but also by doing literacy activities such as reading or writing. One third of the data phase was coded as writing. Registering data was typically a writing activity and constituted a major part of the phase, thus writing helped to structure the data phase. One of the principles of Seeds/Roots (Cervetti et al. 2006) is to do secondhand investigations by reading about and using data that others have collected. When coding the data material, we saw that in most cases where data were collected during reading, the students actively studied a text, e.g., by observing pictures to collect information that were later used in discussions. Combining the different layers of coding also revealed that the whole range of learning modalities was utilized to implement the preparation phase, indicating that preparing for data collection provided students with rich and varied experiences. Conversely, the discussion and communication phases were mainly dominated by oral activities, which revealed a potential for including a greater range of learning modalities in these consolidating phases.

Key Concepts

Focusing on a limited number of key concepts in each unit is a central principle in the Budding Science and Literacy project. Gaining active conceptual understanding is an essential learning goal for the students in an integrated approach (Pearson et al. 2010). Therefore, it was vital to explore our material to identify any patterns involving key concepts. Our video analyses showed that the teachers focused on key concepts mainly in the preparation and discussion phase. Further analyses revealed that the concepts were introduced during the preparation phase, and that the discussion phase was used to re-address the concepts (see Haug and Ødegaard 2014). However, the time spent on emphasizing key concepts was unequally distributed amongst the teachers. Anna and Birgit excelled by using more time than the other teachers (see Haug and Ødegaard 2014), which indicates that focusing on key concepts was a challenge to some teachers, and that the teacher guides should provide more support on that point.

The Use of Data in the Discussion Phase: An Example

Birgit's class differed from the other teachers', classes in that her class spent more time in the consolidating inquiry phases of discussion and communication, as well as focusing more on key concepts. Therefore it was interesting to examine her class closer (Haug 2014; Haug and Ødegaard 2014). Here it is used as an illustrative example for the readers of how the teacher managed to engage the students in inquiries about systems using the Budding Science and Literacy teaching model (Textbox 1).

During a sequence of several lessons, the focus in Birgit's class changed between the different phases of inquiry. The data phase was mainly followed by discussion or communication, systematically guided by the teacher. In the discussions, the students interpreted their own data, made inferences about their findings, discussed the implications of their results, and connected theory and practice. All these activities are considered central for learning, indicating that the discussion phase has the potential for valuable learning situations (Textbox 1).

Textbox 1. Excerpts (1-13) from a two-hour session in Birgit's class during the Seeds/Roots unit Body Systems showing how the teacher initiates and guides the students' activities through different inquiry phases.

Category of inquiry	Code	Teacher's initiation
1. Preparation	Prior knowledge	Which five senses do we have?
2. Preparation	Prior knowledge	What do we mean by function?
3. Data	Collecting	Observe the wheel on page 4.
4. Discussion	Interpretations	What is the wheel's structure?
5. Discussion	Inferences	Can you say something about its function?
6. Discussion	Implications	Can a wheel without spokes roll?
7. Preparation	Wondering	How can we sort the yellow balls from the blue?
8. Preparation	Planning activity	Make a plan for sorting them.
9. Data	Collecting	Start to investigate how you could make a ball sorting system.
10. Data	Organizing	Make the system you decided on.
11.Communication	Oral communication of results	Present your system and what you were thinking about during the process.
12.Communication	Assessing own work	What were the challenges you encountered?
13. Discussion	Connecting theory and practice	What was the function of the tube in your system? Talk to your peer about that for ten seconds.

In the discussion phase, the teacher ensured that the students used the data they collected, either by studying a picture (see excerpt 3, Textbox 1) or doing a firsthand investigation (excerpt 9 – 10). In this way, the discussion was empirically grounded in the students' own experiences. The key concepts for this learning sequence about body systems were system, function, and structure, and these concepts were also systematically brought into the discussion. In the first discussion, the students used their observations of a picture as data (excerpts 4-6). They interpreted the picture of a wheel and made inferences and discussed the implications of its structure and function. This small inquiry can be seen as preparation for the next more extensive inquiry. The students collected data through experimenting with different ways to make a ball sorting system (excerpts 9 – 10). To connect theory and practice about the functions and systems, the teacher asked the students: “Which function did the tube have in the system you just made? Talk to your peer about that for ten seconds!” (excerpt 13). This way, she made sure that the students’ data and engagement from their experiment were brought into the discussion, and that all the students expressed their thoughts. Afterwards, they shared their ideas in a whole-class discussion.

Summing up results

Several large-scale studies have shown that integrated inquiry-based science and literacy activities give increased learning outcomes in pre- and post-tests with a control class (Cervetti et al. 2012; Fang and Wei 2010). However, the present small-scale study aims at describing what happens at the classroom level during the implementation of an integrated inquiry-based science and literacy curriculum. Thus, our research contribution is to provide an overview of literacy and inquiry activities in our material and offer insight into the integrating processes that occur.

Our analysis revealed that the multiple learning modalities (read it, write it, do it, talk it) were all used in the integrated approach, with a prominence of oral activities. This is connected to the fact that a high number of plenary activities often play the role of scaffolding, modeling, or summing up the other modalities. Thus, oral activities overlapped with the other activities. The inquiry phases shifted throughout the students’ investigations, but less time was allocated to the consolidating phase of discussion. Discussion activities were actually under-used compared to the teacher guides (Figure 3). The multiple learning modalities were integrated in all inquiry phases, mainly in preparation and data, while the discussion and communication phases included mostly oral activities.

Discussion

Prior to offering reflections and discussion, we feel it is important to recognize some of the limitations of the present work. First, we accentuate the fact that this is a small qualitative study, and that even though we report our results as quantities of time applied on classroom activities, the results cannot be generalized directly. The reasons for quantifying our video observations, was to search for variations and patterns in our analysis (Ødegaard et al., 2012), and to be able to compare the implementation of activities with suggestions from the teacher guide. The quantification was also used to provide an overview of our data and form a foundation for further in-depth studies connected to the Budding Science and Literacy project.

Concomitant of claiming that the quality of an activity is more about how it is accomplished than the amount of the activity, we believe that our quantitative results are useful and interesting. The analyses are qualitative interpretations of classroom activities. All coding of the discussion phase for instance, are ascribed incidents where students and the teacher discuss their own data using special strategies that we consider central for scientific thinking (e.g. linking empirical data and theory; making inferences; discussing implications). When our results show that the quantity of these codes are less than anticipated from the teacher guides we can assert that there are less opportunities for the students to consolidate their knowledge. However, our present study does not include individual student comprehension and reasoning outcomes, thus it is not possible to report on learning effects from our classroom analysis. Our main contribution to the research community was to present an overview of how science inquiry and literacy activities were distributed within an integrated approach, as called for by Howes et al., (2009), and offer considerations of the challenges teachers may encounter.

In the following we have chosen to structure the discussion around the challenges we identified during the implementation of inquiry phases and integrating science inquiry and literacy. Further, we discuss implications for the Budding Science and Literacy project in particular and for science education in general.

Challenges in the in the inquiry phase

When analyzing our data, we saw some interesting patterns, especially connected to the data phase of inquiry. Our video analyses showed that collecting data encouraged various learning modalities (Figure 1), and these modalities supported students in exploring science issues. Students did not only collect data (by observation or experimenting) but were also guided to organize and analyze the data in order to answer their specific inquiry question. The ownership of scientific data that emerged through the data phase provided the basis for the students' engaged discussions, and the students were challenged by the teacher to make inferences and connect their results to theory. Several studies of inquiry in science lessons have shown that there has been an overemphasis on the "hands-on" part of inquiry and that this is not sufficient for learning science (Duschl and Gitomer 1997; Minner, Levy, and Century 2010; Ruiz-Primo and Furtak 2007). However, we illustrated that even though collecting data might not be essential in itself, it seems essential as a further driving force for engaging in science learning in future consolidating situations.

Our perhaps most interesting results showed that, on average, little time was spent in the discussion phase. This also coincided with the profile of each individual teacher with one exception; see Figure 2. Compared to the teacher guides, most of the teachers spent less time than suggested in the discussion phase. This indicates that the students experienced less emphasis on discussing the meaning of their findings. Other studies (Duschl and Gitomer 1997; Ruiz-Primo and Furtak 2007) have also reported that teachers seem to focus more on tasks, activities, and procedures than on conceptual structures and scientific reasoning. Crawford (2007) stressed that teachers' conceptions of science may influence how they teach science as inquiry. Thus, if teachers see science mostly as an empirical endeavor they might spend less time discussing and communicating results. The primary teachers in our study have little formal science background; therefore discussions in science may be considered challenging. Teachers with low level of content knowledge are less likely to: know what questions to ask of students; which conceptual difficulties to anticipate; what inferences to make of student answers; and what actions to take to adjust instruction toward the scientific accepted ideas (Ball and Hill 2009; Bell 2000; Harlen and Holroyd 1997). If teachers only know science from their own schooling, they may conceive science as more about scientific procedures than developing scientific explanations, and they might not understand the importance of the discussion and communication phases. In any case, teachers need more support and encouragement to utilize the discussions to foster the students' disciplinary comprehension and engagement.

The findings in a meta-analysis examining the effects of classroom discussion on students' comprehension of text support the significance of discussions (Murphy et al. 2009). The authors concluded that especially discussions designed to acquire information from texts, increased students' talk and comprehension. Merely increasing the amount of student talk, however, did not increase student comprehension. Several of the teachers in our study decreased the amount of time spent on the discussion phase compared to the teacher guide. Consequently, the students were provided with fewer opportunities to engage in discussion strategies, including how to connect their experiences from the data phase to science content knowledge.

Challenges for including multiple learning modalities in inquiry phases

Howes and colleagues (2009) found that one of the challenges teachers experienced when integrating inquiry-based science and literacy was that the literacy learning became privileged to learning science. In our study, we find no indications of a similar pattern. The literacy activities (coded as reading, writing and oral) almost always co-occurred with inquiry codes, indicating that they are part of the science inquiry processes and function as supporting structures. This included for example drawing and writing diagrams of a system the students had explored, registering their own data in a table, or gathering data from a text.

However, the combined analysis of multiple learning modalities and different inquiry phases, revealed that the read it; write it; talk it; do it modalities were not evenly distributed. We observed that the discussion and communication phases included fewer modalities than the other phases and that oral activity dominated. This was also reflected in the teacher guides. The oral domination is not necessarily a challenge as it can be naturally explained (overlaps with the other modalities, see Results), but the deficiency of reading, writing and doing in the discussion and communication phases tells us that the integration is not complete. There is a potential for employing the whole range of learning modalities as supporting structures also in the consolidating phases.

Implications for the Budding Science and Literacy project

Our results indicated that the Budding Science and Literacy teaching program provided support for teaching and learning science, but there was room for improvement. We saw that various learning modalities and inquiry activities were integrated, but the teachers encountered the challenge of finding time and courage to utilize especially the discussion phase to consolidate the students' conceptual learning. As mentioned, teachers' conceptions of science and low level of content knowledge may influence how they teach inquiry (Crawford 2007). Introducing inquiry-based science teaching is challenging, and Crawford calls on the science teacher education to take on the responsibility.

The teachers we studied followed a teacher guide and a professional development course. Still, the majority of the teachers underused the discussion phase. This implies that the Budding Science and Literacy teaching program needs improvement to support and encourage teachers to arrange for students to discuss and understand the meaning of their data. Additional reading and writing assignments could be designed with the goal of discussing interpretations and linking data to theory. It is also possible to include more structured talk it and write it activities, for instance, as suggested by (Knain and Kolstø 2011) conducting student research meetings or using wikis. Role-plays that simulate student research conferences may also structure the discussion phase by including literacy practices of science (e.g. writing applications, designing a poster session, discussing with other “scientists”) (Ødegaard 2003).

Based on our findings, another implication for the Budding Science and Literacy project is that teachers should have complementary professional development focusing on the nature of science issues, including the importance of discussing and communicating for developing scientific knowledge.

Implications for Integrating Inquiry-Based Science and Literacy

In the introduction we pointed to the assertion agreed upon by several researchers, that science and literacy are each in the service of the other, and that science learning benefits from embedded literacy activities (Pearson et al., 2010; Cervetti et al., 2012; Norris and Phillips, 2003). Our study implies that an integrated approach may be effectively accomplished (learning modality codes were coincidental to inquiry codes). This, however, requires supporting structures. Thus, our findings concur with the suggestion of Schneider, Krajcik, and Blumenfeld (2005) that lesson descriptions should be supplemented with education support and professional development.

These results are further confirmed by an in-depth study as part of the present Budding Science and Literacy project. Haug and Ødegaard (2014) showed that students need to actively apply the key concepts through all the phases of inquiry to increase their conceptual understanding. When students became familiar with the key concepts in the preparation and data phases, they were able to use the key concepts in the discussions phase to consolidate their new knowledge. Therefore, to support conceptual learning it is crucial for students to spend time in the discussion phase.

Final comments

Beyond the Budding Science and Literacy project, this article offers an overview of classroom activities during an integrated literacy and inquiry-based science approach. We compared different layers of analyses for multiple learning modalities and inquiry, searching for interesting variations and patterns that were not obvious through observations alone. These patterns showed how students used their data in the discussion and communication phases, how literacy modalities are used in the different inquiry phases, and how teachers supported the students' conceptual understanding. We consider these results interesting and useful for other science education researchers involved in inquiry-based science, science and literacy, or both. The results draw attention especially to the discussion phase of inquiry, reminding us of its importance and how challenging this phase might be when teaching science.

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FARGET SIDE

FARGET SIDE

ARTICLE II

Formative Assessment and Teachers' Sensitivity to Student Responses

Berit Haug and Marianne Ødegaard

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Abstract

Formative assessment, and especially feedback, is considered essential to student learning. To provide effective feedback, however, teachers must act upon the information students reveal during instruction. In this study, we explore how sensitive teachers are to students' thoughts and ideas when teaching for conceptual understanding within a framework of formative assessment. Six elementary school teachers are interviewed and video-taped as they implement an integrated inquiry-based science and literacy curriculum. The curriculum especially emphasizes teaching of key science concepts through different modes of learning. We created four main categories for fostering conceptual understanding: Identifying Learning Goals, Eliciting Student Information, Interpreting Student Information, and Acting. Findings indicate that elementary school teachers with low level of pedagogical content knowledge in science do not know the key concepts of a scientific idea or how to teach them to increase student learning. Subsequently, the teachers' sensitivity to student responses and actions is not likely to be aligned to the scientific idea expressed through the key concepts as learning goals. We suggest that teachers need support to identify key concepts within the discipline of science. It is equally important to realize that these concepts must be taught in a context, linked to other words and concepts, since merely knowing which concepts to teach is not sufficient to promote conceptual learning.

Keywords: formative assessment; conceptual learning; science and literacy, classroom study

Introduction

A vast amount of literature considers formative assessment vital to student learning, and the benefits are largely associated with the positive impact of feedback (e.g. Bell and Cowie, 2001; Black and Wiliam, 1998; Harlen, 2009; Sadler, 1989). To provide effective feedback, however, teachers must act upon the information students reveal during instruction (e.g. Harlen, 2009). Thus, when we examined teachers' instructional practices for promoting and assessing student conceptual understanding in the present study, the main aim was to explore teachers' sensitivity to student thoughts and ideas. Sensitivity is understood as the extent to which the teachers notice and build on features in student thinking related to the scientific idea being taught (Coffey et al., 2011). This is similar to responsiveness, described as an attempt to understand what another is thinking displayed in how the teacher clarifies, questions and probes that what the student has said, with an emphasis on student thinking (Black et al., 2003). The formative assessment literature often assumes that teachers know what to look for in student responses and how to align those responses to the scientific phenomenon investigated. Thus, the substance and quality of the teachers' reactions to information students reveal during instruction is rarely examined or communicated. With this study, we address this absence and build on the critique directed to the missing disciplinary content of formative assessment, claiming that formative assessment has become a strategy focusing more on pedagogical skill than on the content to be taught (Bennett, 2011; Coffey et al., 2011; Duschl, Schweingruber, and Shouse, 2007).

We followed six elementary school teachers as they implemented an integrated inquiry-based science and literacy curriculum. The curriculum emphasizes the learning of a set of pre-selected science key concepts that students meet multiple times through hands on (do it) and literacy (talk it, read it, write it) activities (Cervetti et al., 2006). In our study, these key concepts served as point of reference when exploring how the teachers elicited students' thinking and the type of feedback the teachers provided to foster conceptual understanding in students. In the integrated curriculum, science inquiry implies that students search for evidence in order to make and revise explanations based on the evidence found and through critical and logical thinking (Barber, 2009). Science inquiry serves several purposes (Gyllenpalm, Wickman, and Holmgren, 2009), in this study, inquiry-based science served as the context for conceptual learning and it was not within the scope of our research to focus on inquiry as process or ways to understand nature of science.

Purpose of the Study

With a special interest in teachers' sensitivity to student responses, the aim of this study was to explore how teachers promoted conceptual understanding within a framework of formative assessment. To guide our research we asked the following questions:

- Which features of formative assessment emerge as essential to foster conceptual understanding?
- How does an integrated science/literacy curriculum provide opportunities for promoting and assessing conceptual knowledge?
- How can findings from the present study be transformed into a general model for assessment to support learning in science education?

For the purpose of producing context-based knowledge of how formative assessment supports the development of conceptual knowledge, a qualitative research methodology was employed (Denzin and Lincoln, 2000). Through teacher interviews and video-recorded classroom observations we focused on teachers in their moment-to-moment interactions with the students. How the teachers observed what students said or did and how student responses informed the next instructional step.

Features of Formative Assessment and Conceptual Understanding

In this section, we present an overview of the theoretical perspectives and literature we draw on when analyzing and discussing the empirical data. First, formative assessment and its impact on teaching and learning are addressed, with an emphasis on feedback, the absence of disciplinary substance, and the role of pedagogical content knowledge. Then, we provide a brief overview of the theoretical underpinnings for conceptual understanding in the integrated inquiry-based science and literacy curriculum the participating teachers implement.

Formative Assessment

Over the last decades, a number of definitions of the term formative assessment have been proposed. In a review of formative assessment, Bennett (2011) argues that the term has become somewhat confused, and existing definitions admit such a variety of implementations that effects should be expected to vary widely from one implementation and student population to the next. Our theoretical framework in this study is consistent with what many scholars support, that for formative assessment to take place, teachers must gather and interpret information of students' thinking and then use this information to make instructional decisions for the purpose of helping students toward the learning goals (e.g. Black and Wiliam, 1998; Harlen, 2003; Sadler, 1989).

Feedback

The benefits of formative assessment are largely associated with the positive impact of feedback, which many educational researchers consider the most effective aspect of student learning (e.g. Bell, 2007; Hattie and Timperley, 2007; Shavelson et al., 2008). Type of feedback, however, is crucial, and evidence from various studies shows that some types of feedback are more effective than others (e.g. Black and Wiliam, 1998; Ruiz-Primo and Furtak, 2007). Feedback about the person (usually praise) is least effective (Black and Wiliam, 1998; Butler, 1987; Hattie and Timperley, 2007), while feedback that relates to specific and clear goals and processing of the task (Hattie and Timperley, 2007; Hodgson and Pyle, 2010; Sadler, 1989), focuses on students' ideas (Chin, 2006; Coffey et al., 2011; Harlen, 2003), and offers guidance for improvement (e.g. Bell and Cowie, 2001; Black et al., 2003) is beneficial. Feedback can be provided by teacher, peers, or oneself (e.g. Bell and Cowie, 2001; Black et al., 2003). In this study, feedback refers to information provided by the teacher to students regarding their responses and ideas, and support provided to improve students' conceptual understanding.

Figure 1 illustrates a model based on the theoretical perspectives of formative assessment applied as a guideline for the analysis in this study. The model involves eliciting and interpreting information about students' thinking, and acting on this information by adapting teaching according to students' needs or by providing feedback. Two types of feedback are represented; confirmative and elaborative. The first refers to confirming student answers, while the latter is when teachers elicit more information, and provide guidance and cues to enhance learning.

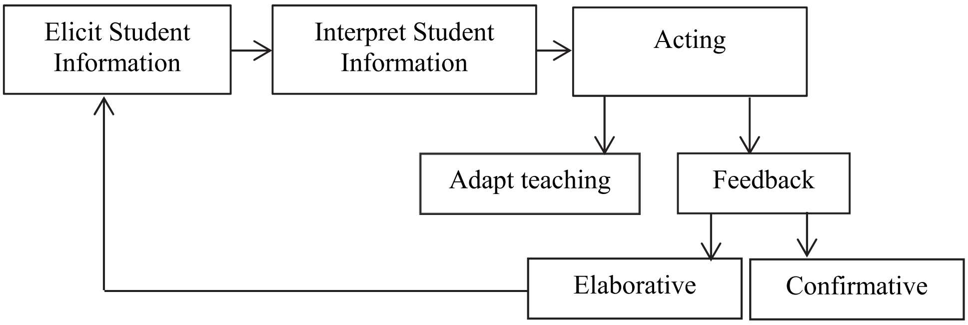

Figure1. Model based on theoretical perspectives of formative assessment. The model involves eliciting and interpreting information about students' thinking, and acting on this information by adapting teaching according to students' needs or by providing feedback. Confirmative feedback refers to confirming student answers, elaborative feedback means to provide guidance and cues to elicit more student information.

Missing Disciplinary Substance of Formative Assessment

Research considers that general practices associated with formative assessment facilitate learning (e.g. Bell, 2007; Black and Wiliam, 1998). Even so, Coffey and colleagues (2011) claimed that formative assessment is treated as strategies and techniques for teachers, and largely disregards the disciplinary substance of what teachers should be assessing. To support this claim, they selected four highly cited publications—Black et al. (2003), Shavelson et al. (2008), Morrison and Lederman (2003), and Bell and Cowie (2001)—and highlighted the lack of attention to student reasoning described in these studies. The critique was directed toward views of content as correct information, and for focusing on strategies that cut across topics and disciplines. Such strategies include wait time or "stop lighting" (Black et al., 2003) or questioning without closely examining the ideas and reasoning they reveal. For effective formative assessment, teachers should consider more in student thinking than the "gap" (Black and Wiliam, 1998) between student thinking and the correct concepts (Coffey et al., 2011; Duschl et al., 2007). This involves sensitivity to *how* students are reasoning about the natural world. Lemke (1990) stated that teachers need to distinguish students participating as budding scientists, trying to make sense of the world as scientists do, from those playing the classroom game accepting ideas on the authority of the teacher and saying what they are expected to say.

Pedagogical Content Knowledge

Many researchers argue that teachers' enactment of formative assessment depends on their level of pedagogical content knowledge (PCK) (e.g. Ball and Hill, 2009; Bell, 2000;

Shepard, 2000). Shulman (1987) has described PCK as the range of knowledge bases teachers need to successfully teach a subject to a specific group of students in a particular discipline. The relationship between possessing the content knowledge and knowing how to teach this content is found to be especially difficult for elementary school teachers (Ball, 2000; Dixon and Williams, 2003). They are required to teach a number of subjects and typically have less subject matter knowledge than those teaching at higher levels of schooling (Magnusson et al., 1999). The teacher's level of PCK affects formative assessment in several ways. Teachers with low-level PCK are less likely to know what questions to ask of students, which conceptual difficulties to anticipate, what inferences to make of student answers, and what actions to take to adjust instruction toward scientifically accepted ideas (Ball and Hill, 2009; Bell, 2000; Harlen and Holroyd, 1997). Additionally, Black and William (1998) state that formative assessment is not well understood by teachers and is weak in practice. Several studies show that teachers need substantial knowledge, time, and support to implement formative assessment effectively in classrooms (e.g. Bell and Cowie, 2001; Bennett, 2011; Shavelson et al., 2008). Considering these findings, we addressed the teachers' level of PCK in our analysis of how teachers promoted conceptual understanding within a framework of formative assessment.

Teaching for Conceptual Understanding in the Integrated Curriculum

The participating teachers implemented an integrated science/literacy curriculum in which students engaged with key science concepts multiple times through multiple modalities (do it, talk it, read it, write it) (Cervetti et al., 2006). Considerable evidence supports the efficacy of an integrated curriculum, both in terms of literacy and science outcomes (Cervetti, Barber, Dorph, Pearson, and Goldsmith, 2012a; Magnusson and Palincsar, 2004; Yore et al., 2004). When science content is addressed through a combination of inquiry and literacy activities, students learn science concepts in-depth simultaneously as they learn how to read, write, and discuss within an inquiry-based setting (Cervetti et al., 2012a; Norris and Phillips, 2003). To support the development of conceptual knowledge, Cervetti et al. (2006) stressed the importance of teaching the key concepts highlighted in the curriculum in a context and in relation to other words within the discipline. In traditional science instruction, concept learning is sometimes reduced to acquiring the definitional knowledge of a large number of words (Cervetti et al., 2006). According to the work of Vygotsky (1986), studying words out of context puts the learning process on the purely verbal plane. Rather than developing the students' thinking, this method encourages only a reproduction and recollection of established definitions. When exploring how teachers promote and assess conceptual understanding in this study, the science key concepts and how they are taught are central. This is closely linked to features of formative assessment. How the teachers elicit and interpret students' understanding of the concepts ultimately guides the teachers' further actions, including the type of feedback they provide to help students contextualize and interconnect the concepts necessary to develop conceptual knowledge.

Methods

In the Methods section, we present the context of the study, including a detailed description of the teaching material implemented. Then, the participating teachers are introduced before we discuss the data collection procedures and the data sources we used. Finally, we give a thorough explanation of our analyses.

Context of the Study

The study takes place in Norway and is part of a larger project aiming to test and refine a teaching model that integrates inquiry-based science and literacy, the Budding Science and Literacy project (Ødegaard and Frøyland, 2009). This project builds largely on curriculum materials from the teaching program Seeds of Science/Roots of Reading[1] (Seeds/Roots) developed at Lawrence Hall of Science, Berkeley. Included in this program is systematic and detailed curriculum material, introducing a do it (hands-on), talk it, read it, and write it approach to science teaching and learning. The focus on inquiry and literacy skills is in line with the Norwegian National Curriculum[2] that emphasizes inquiry-based science and integration of reading, writing, and talking in every subject, including science. The Budding Science and Literacy project invited elementary school teachers to participate in a professional development course focusing on integrating inquiry-based science and literacy. As part of the course, the teachers implemented and adapted teaching materials from Seeds/Roots to the local context of their classrooms (e.g., language, students' age, time and tools available, national curriculum, school policies). Six teachers from four different schools volunteered to be interviewed and videotaped before, during, and after the implementation. Before the data collection, the participating teachers, parents on behalf of

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[1] http://www.scienceandliteracy.org

[2] http://www.udir.no/Stottemeny/English/Curriculum-in-English/

the under aged students, and the principals signed an informed consent form agreeing to the videotaping of the classroom instruction for research purposes. All names in the study are pseudonyms.

Teaching Material

The Seeds/Roots curriculum the participating teachers implemented consists of a number of units covering several topics within life science, physical science, and earth science. All units rest on the principle of integrating inquiry-based science and literacy, and the materials are designed to address key science concepts multiple times through multiple modalities (do it, talk it, read it, write it) (Cervetti et al., 2006). The key concepts consist of words that are central to science and necessary for understanding the scientific ideas (e.g., force, gravity, property, system), and the processes (e.g., investigate, data, evidence) being taught. A detailed step-by-step teacher's guide that includes instructional strategies and embedded assessment comes with every unit. Even though formative assessment should be an ongoing activity during lessons (e.g. Bell and Cowie, 2001), there are steps where the teacher's guide explicitly point to the importance of all students reaching a level of understanding before moving on. The teacher's guide provides examples of what to expect from students at specific stages in the unit. For example, in a unit called *Gravity & Magnetism,* where two of the key concepts are *forces* and *evidence*, the guide says: "Students should now be able to identify a variety of pushes and pulls from the pictures in the book as evidence of forces."[3] It also offers suggestions for how to provide more experience and support if necessary, e.g.: "If students struggle help them to locate evidence of forces, and encourage them to ask themselves if they see a pull happening in this page, or a push."[4] Additionally, included in the teaching materials are investigation notebooks for the students that teachers can use to collect evidence of student learning. Finally, the teaching materials are designed to help teachers to apply entire cycles of inquiry in which students learn to ask researchable questions and conduct investigations to search for evidence that can help answering their questions.

[3,4] *Gravity and Magnetism,* Teacher's Guide, session 1.4, p. 81. Seeds of Science/Roots of Reading.

Participants

The six teachers we followed (Table 1) were part of a cohort of 22 elementary school teachers. The teachers attended a year-long professional development course (PD) and met once a month for lectures and practice related to the integration of inquiry-based science and literacy in the classroom. As part of the PD course, the teachers selected sessions from a unit of their choice to teach in their classroom. None of the teachers had any science background; they were generalists teaching all subjects in elementary school (6–12 years old). Years of teaching experience varied among the teachers, from a novice in her second year of teaching, to experienced teachers with more than 20 years of practice (Table 1). There were only female participants at the course, which is not surprising since 90% of elementary school teachers in Norway are women[5]. The typical participant attended the course with one or several colleagues from the same school, as intended by the course developers to create opportunities for the teachers to cooperate. All the schools were located within two neighboring counties with comparable conditions regarding resources for schooling. The students were mainly ethnic Norwegians.

Table 1. Background information for participating teachers (pseudonyms)

School	Teacher	Grade (age)	Years of Teaching Experience	Number of Students	*ECTS Credits in Science
A	Anna	5 (10–11)	0–5	14	16–30
B	Betsy	1 (6–7)	11–15	18	16–30
B	Birgit	4 (9–10)	11–15	24	16–30
C	Cecilia	3 (8–9)	20+	19	16–30
E	Ellinor	3 (8–9)	11–15	16	31–60
E	Emma	3 (8–9)	20+	21	16–30

*Credits in science are achieved as part of initial teacher education

Data Collection and Data Sources

To answer our research questions, we collected empirical material through multiple qualitative data collection methods (Denzin and Lincoln, 2000) (Table 2). The main data source stems from transcripts of individual audiotaped interviews from the six teachers (Table 1) in which they reflect upon their own instructional practice. This is supported by videotaped classroom observations of the teachers interviewed. In addition, we had access to data from all 22 participants in the PD course, consisting of an open-ended questionnaire, reflection notes, course papers, and video-recordings of teachers presenting

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[5] The Norwegian Directorate for Education and Training. https://gsi.udir.no/tallene/#

their experiences with the implementation process. These sources were used as supporting data and compared to findings from the interviews.

Table 2. Data collection and data sources

Unit of Analysis	Data Sources	Timing	Participants (N)
Description of science teaching practice	Interviews	Pre- and post-implementation	6
	Questionnaire	Pre-implementation	22
	Written reflections	Post-implementation	22
	Paper/presentation	Post-implementation	22
Enacting science teaching	Video recordings	During implementation	6
Sensitivity to student responses	Interviews	Pre- and post-implementation	6
	Video recordings	During implementation	6

The six teachers are interviewed twice, first in the early part of the professional development course, and then again within a few days after they finished implementing the teaching material. This ensured that the implementation process was still fresh in mind, and since the interviewers (the authors) were present in the classroom during implementation, there was a common understanding of references made by either the interviewer or the interviewee. We developed and applied a semi-structured interview guide for each interview, which lasted between 40 and 55 minutes each. The first interview invited the teachers to reflect upon their daily practice regarding strategies for promoting and assessing science concepts, and especially their sensitivity to student responses. The second interview focused on the same, with emphasis on the teaching material.

The purpose of the video recordings was to more clearly understand what was going on in the classroom and to confirm the consistency between teachers' saying and doing. Two cameras in the classroom provided data for this study: One small wall-mounted camera faced the students, and one camera followed the teacher. The wall-mounted camera had satisfactory audio recordings, while the teacher wore a small wireless microphone that was linked to the teacher camera. This captured almost all teacher talk during the lesson, as well as most student talk. Altogether, there are 35 hours of video recordings evenly distributed among the six teachers.

Analysis

The analysis is guided by our research questions and the overarching aim of exploring teachers' sensitivity to student responses when promoting and assessing conceptual understanding. Transcripts from the interviews are the main sources of analyses, while segments from the additional data sources are included when applicable, informing the study and establishing credibility. The triangulation of data sources and analyses ensured rich, robust, and comprehensive data that allowed us to check for consistency and, equally important, inconsistency in the findings. Various analyses were applied to the data retrieved from the interviews and videotapes, which elucidated several aspects of the same phenomena and contributed to enhance the study's credibility (Berkowitz, 1997; Bogdan and Biklen, 2003).

Drawing on theoretical perspectives on formative assessment, we read and reread the interviews to search for emerging themes that might help us understand teachers' emphases on different aspects related to teaching practice. To capture how respondents think about their own practice, we used some of their own phrases to label codes in the initial coding process, as suggested by Bogdan and Biklin (2003). This could be common topics emerging in responses about specific matters, for example, codes regarding formative assessment of student understanding such as "I listen when students discuss" or "I believe they understand." Then, codes for similar content were grouped into new codes created to highlight information on teaching practices, including sensitivity to student responses and level of PCK. Finally, these codes were adapted into overarching categories in an iterative process moving in and out between the data sources and analysis until redundancy (Strauss and Corbin, 1994) (see Table 3 for codes and categories). The categories were systematically applied to each interview transcript and additional data sources where applicable (questionnaire, reflection notes, course paper, and transcript of teacher presentations). Due to the study's design and to answer the research questions, we distinguished between teacher responses referring to before and after the intervention within each category. The intervention is the professional development course including the implementation of the integrated curriculum.

The next move was to look for patterns within each category, and how these patterns, or lack thereof, could help illuminate our questions (Berkowitz, 1997). Analyzing transcripts from interviews, written papers, and presentations did not provide sufficient data on teachers' sensitivity to student responses during instruction; thus, we went to the video recordings to see what instruction looked like from a classroom perspective. To reduce the workload of going through countless hours of video when selecting episodes to analyze, we based our selection on available information, as recommended by Derry et al. (2010). From the teacher's guides, we identified embedded assessment points connected to assessing students' understanding of science concepts, because teaching of science concepts is accentuated in the teaching material and central to this study. We also used the categories created from the interviews as guidelines to inform the search. Four teaching sequences were eventually considered representative and significant to inform the study.

Findings

When analyzing the interviews, we identified several codes describing practices linked to promoting and assessing student conceptual understanding. Based on these findings and our theoretical perspectives on formative assessment, we created four categories. They were labeled Identifying Learning Goals, Eliciting Student Information, Interpreting Student Information, and Acting (see Table 3). We describe these categories thoroughly in the following sub-sections.

Since we looked at pre- and post-intervention, findings are presented to elucidate changes in teachers' instructional practice. First, we found that statements across the different data sources (interviews, reflection notes, papers/presentations) were consistent regarding instructional practice before trying out an integrated science/literacy curriculum as well as after. The interviews served as starting point and information related to what teachers stated in the interviews was traced in the other data sources and compared to the initial statements when applicable. Furthermore, as the analysis is conducted by coding segments of text organized in codes and categories, the examples presented in Table 3 may represent the speech of more than one person as it is a segment of talk rather than the contribution of a single person. From transcribed video recordings, we present four excerpts from three different classrooms, different units, and different teachers. The excerpts demonstrate single events, but represent examples of several observations. Results from the interviews are organized in Table 3, while the results from video recordings are described in each sub-section. We summarize our findings at the end of the section.

Table 3

Codes for teachers' description of their practice prior to and after the intervention, illustrated with examples and grouped into overarching categories

Category	Description	Codes	Examples Pre-intervention	Examples Post-intervention
Identifying Learning Goals	Involves how teachers select words and concepts to teach, and on what they base their selection	Selecting concepts to teach	"Words that pop up in a conversation or in a text, words that I don't think they understand."	"The pre-selected key concepts help me know what they need to learn in order to understand the things we are discussing."
		Teachers' presuppositions of students' prior knowledge	"I know what my students know." "If they don't understand, they ask."	Not addressed
		Teachers' pedagogical content knowledge	"Concepts are important in science." "It is a little bit hard in science (to select key concepts) since I don't know science that well."	"Often there's a jumble of concepts in textbooks, and I don't know if they are equally important, so to know which words to focus on was really helpful."
Eliciting Student Information	Involves teachers' description of activities to make student thinking and understanding visible, and how this is applied	Activities to make student thinking visible	"When they talk, they reveal what they know." "The best, and maybe only way, to collect information on what students know is a written test."	"I notice what students know when they discuss in groups or whole class. "The writing activities revealed what the students understood"
		Teacher/student focused	"I ask them to discuss." "I ask them questions when I summarize the lesson."	"The students demonstrated what they understood, especially through the written tasks, but also when they discussed their findings."
		Teachers' pedagogical content knowledge	"Sometimes when they start to ask questions I feel insecure."	"When I know what is important to learn, the core, then I can open up for all kinds of ideas, because I know how to guide them back on track."

Category	Description	Codes	Examples Pre-intervention	Examples post-intervention
Interpreting Student Information	Information about how teachers make sense of the information students reveal, and what kind of information they are looking for	Student responses	“I’ve been a teacher for so many years, so I just know, like, the way they talk and the way they act.”	“When students discuss in groups, I observe how they apply the key concepts.”
		Teachers’ presuppositions of student understanding	“It’s more like a gut feeling.” “I can tell if they understand based on their body language.”	Not addressed
		Aligned to learning goals	“In math and language arts, there are specific goals, it would be easier if we had the same in science.”	“If students use the key concepts in their talk, I consider it as reaching the learning goal.”
Acting	Involves teachers’ descriptions of how they provide feedback and adapt their teaching based upon elicited and interpreted student information	Feedback	“I often ask them to explain what they mean.” “It’s important to provide positive feedback to motivate the students.”	“I give them feedback to let them know they did a good job.”
		Adapt teaching	“In math, I know the answer and where to lead the students. It is harder in science where the answer can be almost everything, well, not everything, but much more than I know and can explain.”	“They don’t always get it right the first time, so I have to help them say it the right way.”
		Aligned to learning goals	Not addressed	“I know which students to ask to get the answers necessary to move on.”

Identifying Learning Goals

The first category, *Identifying Learning Goals,* refers to recognizing science key concepts necessary for conceptual understanding of the phenomenon being taught. We examined teachers' practice when they selected which concepts, or science words, to emphasize, and how these words were taught to make sense of their meaning. Teachers spoke openly about their lack of a specific approach when teaching science concepts before the intervention, even though they acknowledged the importance of learning concepts in science and in other subjects. The selection of words to accentuate and explain was more or less random, and mainly based on teachers' presupposition of students' knowledge (see Table 3). The key science concepts important for understanding the scientific idea being taught were not identified by the teachers as learning goals. Thus, the words and concepts students need as guidance to conceptual understanding is not explicitly addressed or communicated to the students, something the literature refers to as essential for learning (Harlen and Holroyd, 1997; Lemke, 1990). After the intervention, the teachers in our study accentuated the improvement the pre-selected concepts in the integrated curriculum made to their teaching. They no longer referred to their presuppositions of students' prior knowledge, but emphasized that the pre-selected concepts provided a direction that helped the students and the teacher better understand the science topic explored. The key concepts were clearly recognized as learning goals by the teachers. They knew what to address and what to assess; thus, they were more confident and found it easier to support student learning.

We examined the video recordings to collect more information on the improved opportunities the integrated curriculum provided for teachers regarding concepts to emphasize. The excerpt is from a lesson in a 3rd-grade classroom (8-year-olds). The unit taught was *Designing Mixtures,* where key concepts introduced include *properties, material,* and *substances.* In the selected episode, the students sat in a circle on the floor while the teacher was checking students' understanding of the key concepts by writing student responses on a flip chart. The embedded assessment point in the teacher's guide stated that at this point students should be able to connect the properties of an object to the material it is made of. We also know that in the previous session the day before, the students worked on connecting properties and material in written and oral activities.

Excerpt 1

Teacher Emma (T): Do you remember what properties were? What could properties be?

Maya: How it smells

T: Yes, let's take that first (writes "smells" on the flip chart)

Christian: Feels

T: Feels, yes (writes). You remember a lot, I'm impressed.

(Listing of different properties goes on for a couple of minutes).

T: Ok, and what was material? What did that mean? Do you remember, John?

John: Like rubber?

T: Yes, rubber could be a material. But what is a material? Ida.

Ida: It is what things are made of.

T: Yes, what things are made of. Do you remember any materials? Dina.

Dina: Metal.

T: Yes (writes metal on the flip chart). Thea

Thea: Iron

(After suggesting some more materials, the students go back to their seats for another task.)

At this point in the unit, students were expected to connect the properties of an object to the material it is made of; however, the teacher never requested such connections. The students were not challenged to use the words actively and link them to make meaning of their relationship. Which words to focus upon is identified and communicated to the students, but conceptual understanding is not supported since no links were made to other science words and concepts (Cervetti et al., 2006; Vygotsky, 1986). Thus, this excerpt shows that the teacher interpreted the learning goals as isolated science words, and not as science concepts as intended by the curriculum.

Eliciting Student Information

The second category, *Eliciting Student Information,* consists of activities teachers applied to make student thinking visible. Before the intervention, when talking about eliciting student information, the teachers mainly emphasized which pedagogical activities *they* orchestrated, and not what these activities led to in terms of disclosing student thinking. The teachers most commonly referred to how they usually asked students to discuss a topic or how they asked control questions to check what the students recalled of the lesson during summing up sequences (Table 3). Among the teachers, classroom talk was referred to as a preferred method for observing students use and understanding of new science words. However, a written test was considered the best, and, for some, the only way to collect information that provided valid information on student learning (see Table 3). Using tests instead of trusting their own observations of students' learning process and the products of their thinking is, according to Harlen and Holroy (1997), typical for teachers with low confidence in a subject. After trying out the integrated science/literacy curriculum, teachers emphasized the opportunities provided by the different modes of representation (do it, read it, write it, talk it) to observe students' thinking and understanding. Except for a few still concentrating on *measuring* students' understanding (e.g., thumbs up/down, summative tests), teachers emphasized how learners demonstrated their understanding when engaging in hands-on activities, discussions, presentations, log-writing, etc.

When going through video recordings to check for consistency between teachers' saying and doing, we found several examples of students engaged in different activities related to their investigations. However, teachers did not always grasp the opportunities these activities provided to enhance student learning. An example of this is provided in the following excerpt from a 5th-grade classroom (10-year-olds). The unit taught was *Gravity & Magnetism* in which one of the key concepts is *force.* The students were engaged in a hands-on activity exploring how forces act between two objects as a push or a pull using blocks with screw hooks, a spring, and a rubber band. The teacher circulated as students worked in groups.

Excerpt 2

Teacher Anna (T): Have you thought about how to do it without using the hooks? (Students show by putting the spring between the blocks, push, and let go).

T: Yes. And what kind of force was that an example of? Push or pull?

Thor: Was it a push?

Liv: It was a push or a pull.

T: (Takes the blocks and push them together with the spring in between). If you do like this and want to have the blocks closer? (Teacher walks away).

This activity revealed that the students were confused about how push and pull relates to the concept of force. When the teacher asked what kind of force they observed, the students just guessed. The teacher did not follow up the student information she elicited, she left the students without any further actions. We observed in the videos what the teachers stated in the interviews; that the do it, talk it, read it and write it approach provided access to student thinking. However, initiating activities without acting upon the student information they produce do not promote student understanding. Instead, the activities become merely pedagogical activities without any substance (Bennett, 2011; Coffey et al., 2011).

Interpreting Student Information

Within the category *Interpreting Student Information*, we grouped teacher statements regarding how to make sense of student responses, how to interpret the information students revealed during instruction, and what kind of information to look for. Overall, the participants found it difficult to articulate how they interpreted student understanding. Especially in the first interview the majority of teachers referred to their long experience as teachers, basing their judgment on students' body language and behavior, and what they called "more like a gut feeling" (see Table 3). This is consistent with what Bell and Cowie (2001) found in their study; formative assessment is largely a tacit process, and teachers cannot explicitly describe how they do it. With the integrated curriculum's focus on introducing key concepts multiple times through multiple modes (do it, read it, write it, talk it), the teachers found multiple opportunities to assess students' understanding. The teachers accentuated the discussions, in whole class and in groups, and the written tasks connected to the hands-on activities as valuable for this purpose. With the key concepts highlighted in the curriculum, the teachers better knew what to look for in student responses. This signifies the importance of identifying the learning goals and to realize that learning requires more than just putting pedagogical activities to work without explicitly knowing why, how, or what they are supposed to accomplish.

To check for consistency between teachers' saying and doing, we examined the video recordings. We looked at how teachers elicited student thinking and interpreted information students disclosed on their thinking aligned to learning the key concepts highlighted in the teaching material. The excerpt is from a 3rd-grade classroom (8-years-old), and the unit taught was *Variation and Adaptation* where key concepts introduced included *variation, adaptation*, and *characteristics*. In this example, the teacher summed up by asking students what they had learned after sitting in small groups looking for variation in six different birds depicted on cards. The embedded assessment in the teacher's guide states that at this point students should be able to describe multiple examples of differences and similarities between organisms and link this to where they live and what they eat.

> *Excerpt 3*
>
> Teacher Cecilia (T): What differences did you see, or observe? (many students raise their hands)
>
> Emma: One is big, and one is small.
>
> T: Yes. Different sizes. Daniel.
>
> Daniel: This is an eagle and this one...
>
> T: This one with red breast?
>
> Daniel: Yes. It is that this one is bigger, and this one is smaller, and this one eats like …worms, and beetles ….and this one eats birds.
>
> T: Yes. You think it looks like that because of the beak? Yes. Ella.
>
> Ella: Different shapes
>
> T: Yes. Different shapes.
>
> (It continues with students identifying different colors, sizes, and shapes.)

Students identified variations in birds, and Daniel attempted to explain why the different birds have different beaks and link this to what they eat. His response was not interpreted or accentuated by the teacher as a step toward conceptual understanding of variation and adaptation. The teacher did not ask for elaboration, she just briefly repeated what she thought he meant. In this talking activity, students revealed what kind of differences they observed and whether they made any links between variation and adaptation. The activity provided the teacher insight into student thinking with ample opportunities for feedback to further the students' understanding. However, the teachers did not recognize, or at least did not address, features in student thinking that could be related to the scientific idea being taught. It seemed as if responses of varying quality were accepted on the same terms with no elaboration or further comments that could enhance students' conceptual understanding. The lack of attention to student reasoning supports Coffey et al.'s (2011) critique of formative assessment as a strategy disregarding the disciplinary substance of the idea being taught.

Acting

There are different ways to act upon the elicited and interpreted student information. We look at action in the form of (a) adapting teaching according to students' needs and (b) feedback to the students. How to act based on assessment information proved to be challenging to link to science education for the participants. Especially in the pre-implementation interviews several teachers turned to mathematics for examples of how to modify their teaching and provide feedback to promote learning (see Table 3). Not knowing what inferences to make of student responses or what actions to take to adjust instruction toward the scientific accepted ideas indicates a lack of PCK in science (Bell, 2000). Many articles emphasize that it is problematic for teachers with low-level PCK to use formative assessment effectively to promote student understanding (Ball and Hill, 2009; Harlen and Holroyd, 1997; Shepard, 2000).

Teachers recognized feedback as an important aspect of teaching and learning, mainly as a one-way process, where the focus was on what they as teachers were doing; they often asked students to explain their thinking, and they provided feedback to student responses. The feedback, though, was mostly in the form of praise to motivate the students and not primarily to elaborate on students' thoughts and ideas. Teachers said they often took pieces of information from student responses that were close to what they were looking for and adapted this to the "correct" answer. This focus on what teachers do, instead of what they see and notice in student understanding, is exactly what Coffey and colleagues (2011) criticized when they referred to the missing disciplinary substance of formative assessment. Adding to this, when the teacher's guide suggested checking for understanding, teachers usually asked two or three students, often identified as knowledgeable, to get the answers necessary to move on (exemplified in Table 3 under *Acting*). This indicates a focus directed toward the progress of the class through the curriculum rather than students' needs (Bell and Cowie, 2001). Through the different activities students engaged in as suggested in the integrated curriculum, teachers trusted they had collected enough evidence of student learning. The student information, however, was not used for further action other than feedback in the form of praise, the least effective type of feedback for student learning (Black and Wiliam, 1998; Butler, 1987; Hattie and Timperley, 2007).

To confirm the results from the interviews, we examined the videotapes from the classrooms. The selected episode is from the same 5th-grade classroom (10-year-olds) as in excerpt 2, where the unit taught was *Gravity & Magnetism*. Key concepts introduced include *forces*, *claim*, and *evidence*. The class was at the end of reading aloud a book that depicted a range of examples of forces as pushes and pulls acting between objects. Throughout the reading, the teacher had stopped at each page and discussed evidence of forces at work with the whole class. The teacher's guide says that students should now be able to identify and demonstrate an understanding of forces as pushes and pulls acting between objects.

> *Excerpt 4*
>
> Teacher Anna (T): Can any of you (reads from the white board): Provide an example of forces acting between two objects, and evidence for your claim? Do you remember some of the things we read in the book? (No one raises their hand, and after a couple of seconds, the teacher continues.) For example, on the soccer field, how do forces act between two objects there? Ina.
>
> Ina: If the ball comes toward you, then you can kick it, and it changes its direction (depicted in the book).
>
> T: Mm. Then we have evidence for forces acting between the ball and the leg. Do you recall anything else? Max.
>
> Max: Balloon and hair (depicted in the book and demonstrated by the teacher).
>
> T: Yes. Balloon and hair. The hair moves toward the balloon without them touching each other. And what is that force called? Magnus.
>
> Magnus: Electrostatic force.
>
> T: Yes.

The example shows that the teacher took bits and pieces from student answers and turned them into the correct phrase she was looking for. She was attentive to the responses but transformed them in a way that made the meaning quite distinct from what the student said. Coffey and colleagues (2011) referred to this as accentuating the wording instead of the substance of ideas, when a right answer becomes the target instead of focusing on student reasoning. The video recordings supported what we found in the interviews: The feedback provided was confirmative, and it was the curriculum, not student understanding, that decided when to move on to the next topic.

Summary of Findings

When comparing pre- and post-interviews, we see how teachers after the intervention expressed an increased focus on key concepts and on students demonstrating their understanding (Table 4). Before the intervention, teachers' attention revolved more around their own instruction and what they as teachers were doing. Teachers also described their teaching as aligned to the learning goals, learning key science concepts, after the intervention. However, video observations revealed that the key concepts were often taught in isolation and not linked to other words and concepts, which is necessary for conceptual understanding (Cervetti et al., 2006; Vygotsky, 1986).

Table 4. Summary of findings from interviews and video recordings organized according to the categories identified

	Experienced by Teachers		Observed by Researchers
	Interviews		Video recordings
	Pre-Intervention*	Post-Intervention*	During implementation
Identify Learning Goals	No specific approach when selecting science words to accentuate.	Pre-selected key concepts.	Pre-selected key-concepts, taught as isolated words, not concepts.
Elicit Student Information	Focus on what teachers do. Written tests are considered the best way to gather assessment information.	Focus on what students disclose. Student thinking made visible when engaging in different activities.	Focus on what students do. Student thinking partial displayed through the different activities.
Interpret Student Information	Often based on students' body language and teachers' "gut-feeling". Not aligned to learning goals.	Based on information elicited through activities. Aligned to learning goals (key concepts).	Based on information elicited through activities. Not aligned to learning goals.
Acting	Confirmative feedback, mostly in the form of praise to motivate the students.	Confirmative feedback, mostly praise.	Little or no action taken to elaborate student thinking or adapt teaching. Confirmative feedback, praise.

*Intervention means the professional development course, including implementation of an integrated inquiry-based science and literacy curriculum.
The interviews represent the teachers' voice; the video recordings are observations made by the researchers.

Based on our empirical findings, we modified our model of formative assessment depicted in Figure 1 (p.4). The modified version (Figure 2) builds on the four categories created from the analysis of teacher interviews and illustrates what we observed in the classrooms:

teachers identified the key concepts as learning goals, elicited student information, and interpreted the elicited information. Teachers' interpretation of student responses, however, was not aligned to the learning goals, which involves teaching the identified key concepts in ways that promotes conceptual understanding. Since we cannot directly observe what teachers are thinking, our result is based on teachers' further actions. There are few, if any, observations of teachers adapting their teaching when students reveal a lack of understanding for how the different concepts are interconnected. Additionally, feedback as praise dominates, and sometimes no feedback is provided at all.

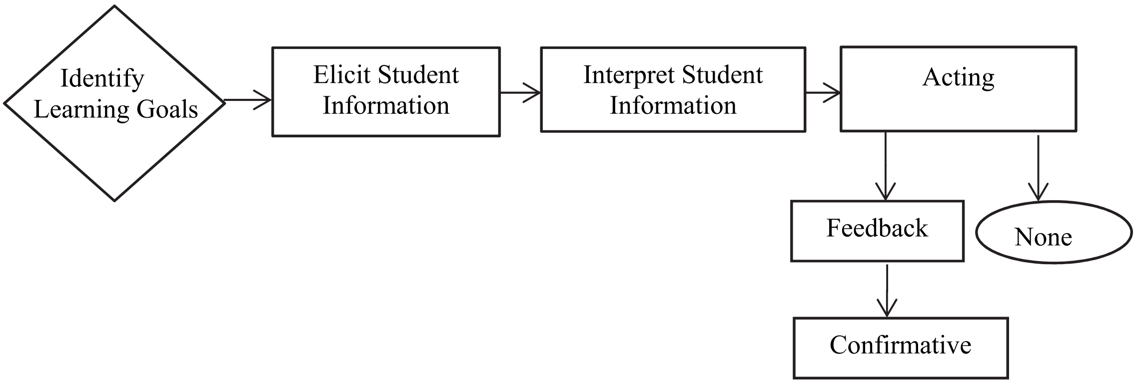

Figure 2. A modified version of the formative assessment model based on observations in the classrooms. The teachers identified science key concepts as learning goals, elicited and interpreted student information. Teacher responses were confirmative feedback or none at all.

Discussion

With an emphasis on teachers' sensitivity to student responses, we start the discussion concentrating on essential features necessary to promote conceptual learning. Second, we discuss changes teachers experienced in their practice as a result of implementing the integrated science/literacy curriculum. Finally, based on our findings and theoretical perspectives of formative assessment, we present a model linking central building blocks of the assessment process to student learning.

Essential Features When Teaching for Conceptual Understanding

The four categories identified as essential for promoting and assessing conceptual understanding are Identifying Learning Goals, Eliciting Student Information, Interpreting Student Information, and Acting upon the elicited and interpreted student information. The process in which teachers gather and use information on student learning to make instructional decisions is essential within formative assessment. However, few authors explicitly point to the need for *teachers* to identify and interpret the learning goals to support students' learning processes. Based on findings in this study and related research addressing elementary school teachers' level of content knowledge and pedagogical content knowledge (e.g. Ball and Hill, 2009; Bell, 2000; Harlen and Holroyd, 1997), we suggest that it cannot be implicitly assumed that elementary school teachers with no science background immediately know the key concept of a scientific idea or how to teach it. Without an articulate understanding of what the key concepts are, and how to address and assess them, formative assessment cannot be expected to promote learning or increase student understanding. Thus, one implication of our findings is that teacher educators, curriculum developers, professional development, and textbook authors need to support elementary school teachers to identify key concepts within the discipline of science. Equally important is to realize that merely knowing which concepts to teach is not sufficient to promote conceptual learning; the concept must be interpreted in relation to other words and concepts. Key science concepts should be taught in a context and not in isolation as a long list of words to remember. Learning science words one-by-one as exemplified in excerpt 1, is referred to as the traditional approach to concept learning in science (Cervetti et al., 2006)), which limits the possibilities for learners to foster deeper understanding of science concepts. When single science words become target information, the emphasis is on terminology rather than the rationality of student reasoning. This is at odds with research on learning, and as Coffey et al. (2011) state, it is at odds with disciplinary practices.

The second key feature when teaching science concepts is to elicit evidence of learning. Gaining access to students' thinking to clarify their existing ideas is a central part of teaching for conceptual understanding (Bell, 2007; Driver et al., 1994). Findings presented in excerpts 2 and 3 in this study, indicate that the teachers design opportunities to gather evidence of student learning; however, their objective is not always clear. To support conceptual learning, the activity of eliciting student information must have an explicit rationale. If the information sought is not aligned to the learning goals and if teachers are not engaging in the substance of students' ideas, the strategies become more an end in itself than a means to an end. The activity of eliciting is not sufficient to promote or assess students' conceptual learning, an argument emphasized by authors critiquing the formative assessment literature for missing the disciplinary content (Bennett, 2011; Coffey et al., 2011). These authors claim that the literature primarily discusses strategies and techniques for *how* to elicit student information, rather than focusing on *what* is being elicited.

To promote conceptual learning, teachers should be able to interpret the information they collect on student thinking during instruction. Thus, the third category is interpreting student thinking. This involves making sense of student responses and aligning them to the learning goals, which in this case is learning of key science concepts. Furthermore, it includes an awareness of the instructional actions required as a response to the interpreted information. Some of the challenges observed among the teachers in this study were linked to their understanding of teaching science concepts in a context of related words and concepts to make meaning of new knowledge. This is demonstrated in excerpt 1 where properties and material are taught in isolation and in excerpt 3 where variation in birds is not linked to adaptation. When teachers teach concepts as definitional knowledge, their interpretation of students' responses and actions, subsequently, is not likely to be aligned to the scientific idea expressed through the learning goals. Therefore, to support teachers in promoting conceptual learning, key concepts for the scientific idea being taught must be clearly stated and operationalized in the curriculum. This finding adds on to what is already suggested by many researchers. Teachers with a low level of content knowledge in science require support for what to look for in student responses as evidence of understanding (Bell, 2000; Harlen and Holroyd, 1997; Shepard, 2000).

The final main feature for supporting conceptual learning is to act upon elicited and interpreted information. This is considered the central aspect of formative assessment, and the typical action is feedback from teacher to students (Bell and Cowie, 2001). In the interviews, the teachers reported that providing feedback was primarily undertaken as an act to motivate students, which is consistent with findings by other authors (Black and Wiliam, 1998; Butler, 1987). To support conceptual understanding, scholars advocate that feedback must be related to specific and clear goals, focus on student ideas, and offer guidance for improvement (e.g. Harlen, 2003; Hattie and Timperley, 2007). This is additional evidence for why teachers' identification of learning goals is crucial when assessing and promoting conceptual knowledge. The nature of feedback necessary to support student learning requires knowledge of the idea behind the learning goals. Our findings also indicate that teachers say they know the students' level of understanding, however, as exemplified in excerpt 2, they do not always act on this information. Since feedback is considered the single most effective aspect of student learning, an important opportunity for promoting students' conceptual understanding is lost when feedback is omitted. Heritage, Kim, Vendlinksi, and Herman (2009) and Shavelson et al. (2008) found that although teachers can make reasonable inferences about student understanding, they face difficulties in making appropriate instructional moves. A suggested explanation is that these teachers lack the necessary pedagogical techniques or content knowledge to sufficiently challenge and respond to the students.

Changes in Teaching Practice with an Integrated Science/Literacy Curriculum

From the teachers' point of view, the major changes caused by the integrated science/literacy curriculum were (a) the pre-selected set of key concepts serving as learning goals and (b) the increased access to student thinking as students engaged in different modalities (doing, reading, writing, talking) (see Table 4). With a pre-selected set of key concepts as learning goals, the teachers stated that they felt more confident in their teaching since the concepts served as a guideline for their teaching. Thus, the teachers experienced that the curriculum provided important support when promoting and assessing science concepts. Such support is recommended in several studies and considered necessary for teachers with low-level content knowledge (e.g. Ball and Hill, 2009; Bell, 2000). Teachers also emphasized how the variation of modalities suggested in the integrated curriculum made student thinking visible, thus easier to assess. Independent of years of teaching experience, when comparing the pre- and post-intervention interviews, we saw that the teachers' emphasis shifted from concentrating on strategies associated with eliciting information to the information students disclosed when engaging in the different activities. Even though this alone is not sufficient to promote conceptual understanding, it is an improvement in the teachers' assessment practice. These findings concur with studies showing that increased teacher confidence and content knowledge in a particular subject are linked to the teachers' ability to assess students' learning (e.g. Harlen and Holroyd, 1997).

Nevertheless, video recordings revealed that the key science concepts were not identified, promoted, or assessed in a way that fosters conceptual understanding. In addition, the teachers did not use the improved access to student thinking to provide feedback or adapt teaching to students' needs. There are few observations in the video material of students demonstrating evidence of conceptual understanding expressed by interlinking of key concepts and being able to apply new knowledge in a context. Just like Furtak and Ruiz-Primo (2008) documented; simply embedding assessment in curriculum will not automatically lead to student learning. Our findings indicate that the teaching material is necessary, but not sufficient without teachers' unambiguous identification and interpretation of learning goals and sensitivity to student responses to guide instructional decisions.

Teacher educators and professional development courses need to accentuate the importance of teaching concepts in a context to support students' meaning making. Teachers are not able to act upon student responses in a way that can promote conceptual learning until they are trained to teach science concepts within a network of other words and concepts.

Last, when comparing teachers' saying and doing as presented in Table 4, we see that teachers experienced that their teaching was aligned to the learning goals while the video recordings revealed a different result. These findings suggest that teacher educators, professional developers, and researchers cannot assume that pre-service and in-service teachers who use the expected vocabulary to describe their practice actually understand and can enact the practice.

Model of Assessment to Promote Learning

We started out this study with a theoretical framework of formative assessment (Figure 1), which we modified according to our empirical data (Figure 2). Based on theoretical perspectives of formative assessment and our empirical findings, we designed a general model for how teachers can promote learning (Figure 3).

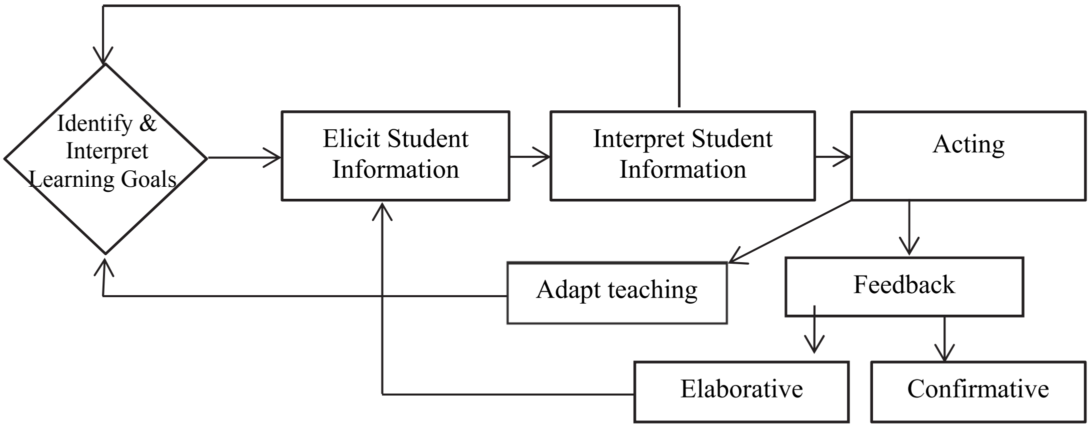

Figure 3. Model based on empirical data and principles of formative assessment. The assessment process is viewed as an iterative one, moving back and forth between the different building blocks indicated by arrows. Compared to the initial model in Figure 1, Identify and Interpret Learning Goals is added including arrows signifying the importance for teachers to align their interpretation of student responses and adapt their teaching according to the learning goals.

The model includes possible pathways dependent on teachers' action. We emphasize that the first step, labeled *Identifying and Interpreting Learning Goals,* is essential for fostering conceptual knowledge. This step is often under-communicated in formative assessment studies. Whereas many point to the necessity of communicating the learning goals to the students (e.g. Harlen, 2003), teachers' identification and interpretation of these goals do not receive the same attention.

To promote learning, we need to recognize the assessment process as an iterative one, meaning moving back and forth between the model's building blocks guided by student responses. This involves what do we want the students to learn (learning goals), where are the students in their learning process (eliciting and interpreting students' thinking), and how do we get to the learning goals (action taken based on the elicited and interpreted information). There are different ways of acting; one is to modify and adapt whole-class instruction based on student responses, or the lack thereof, by returning to clarify the learning goals. This might be to adjust the level of difficulty or to change the mode of representation to reach more students. Another is to provide feedback to students, individually or in a group, as a reaction to information gathered on students' thinking. The nature of feedback varies, and in the model, there are two types, confirmative and elaborative feedback. Elaborative feedback is more effective for learning than just indicating whether the students' work is correct or not as in confirmative (Harlen, 2003; Hattie and Timperley, 2007). However, as Mortimer and Scott (2003) argue, there are some "truths" in science, and sometimes it is necessary for teachers to lead students through a sequence of questions and answers to reach a specific point of view. When the assessment process is iterative, student responses inform teaching and learning: Teachers receive information on their teaching and make decisions on how to adapt the teaching to meet students' need, and students receive elaborative feedback on their thinking to improve their learning. For this to happen, teachers must have an explicit understanding of the learning goals and how to teach them. Therefore, we suggest that an effective formative assessment process rests upon teachers' identification and interpretation of the learning goals. Otherwise, formative assessment is in danger of being a pedagogical activity focusing more on pedagogical skill than on the content to be taught (Coffey et al., 2011).

Limitations

A limitation of this study relates to the small sample. Thus the findings are illustrative and not intended to be representative or generalizable. The results, nevertheless, highlight insights that could add to the knowledge base of the conduct of formative assessment and how to teach for conceptual understanding.

Concluding Comments

Initially, the main focus of our study was how teachers' sensitivity to student responses is related to teaching and learning scientific concepts. Then we gradually realized the importance of teachers' interpretation of learning goals. How teachers interpret and understand the learning goals impact teachers' sensitivity to student responses. This became evident when looking at teachers' sensitivity to student responses and how these responses informed the next instructional step. There are no changes in teachers' action from pre- to post-intervention. This means that teachers barely used their increased access to student thinking to promote learning, either through feedback or by revising instructional decisions. According to the literature, formative assessment takes place only when assessment information is acted upon to enhance student learning (e.g., Bell & Cowie, 2001; Sadler, 1989). Thus, the participating teachers do not perform formative assessment as such. (e.g. Bell and Cowie, 2001; Sadler, 1989). Further research is needed, especially to provide practice-oriented examples that can support teachers with low-level content knowledge how to enact formative assessment in ways that fosters conceptual understanding in students.

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From Words to Concepts: Focusing on Word Knowledge When Teaching for Conceptual Understanding Within an Inquiry-Based Science Setting

Berit S. Haug · Marianne Ødegaard

Abstract This qualitative video study explores how two elementary school teachers taught for conceptual understanding throughout different phases of science inquiry. The teachers implemented teaching materials with a focus on learning science key concepts through the development of word knowledge. A framework for word knowledge was applied to examine the students' level of word knowledge manifested in their talk. In this framework, highly developed knowledge of a word is conceptual knowledge. This includes understanding how the word is situated within a network of other words and ideas. The results suggest that students' level of word knowledge develops toward conceptual knowledge when the students are required to apply the key concepts in their talk throughout all phases of inquiry. When the students become familiar with the key concepts through the initial inquiry activities, the students use the concepts as tools for furthering their conceptual understanding when they discuss their ideas and findings. However, conceptual understanding is not promoted when teachers do the talking for the students, rephrasing their responses into the correct answer or neglecting to address the students' everyday perceptions of scientific phenomena.

Keywords Inquiry · Conceptual understanding · Science and literacy · Video study

Introduction

Over the last decades, good science teaching and learning have become increasingly associated with inquiry (Anderson 2002). Policy documents and curriculum materials around the world are developed based on the idea of inquiry-based instruction as the way to improve science education (Abd-El-Khalick et al. 2004; Rocard 2007). An inquiry-based approach has the potential for students to learn how to *do* science, learn *about* science, and learn *science* by doing science (e.g., Anderson 2007; NRC 2000). In this study, we focus specifically on the aspect of "learning science by doing science," that is, how to teach for conceptual understanding by emphasizing word knowledge development in an inquiry-based setting. The connection

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B. S. Haug (✉) · M. Ødegaard
The Norwegian Centre for Science Education, University of Oslo, P.O. Box 1106, Blindern,
0317 Oslo, Norway
e-mail: b.s.haug@naturfagsenteret.no

between word knowledge and conceptual knowledge is accentuated by Cervetti et al. (2006). They advocate that when science words are taught as concepts, applied in a context and in relation to other science words and concepts, word knowledge is consistent with conceptual knowledge. Learning to use the language of science is vital for learning science (e.g., Lemke 1990; Wellington and Osborne 2001); thus, it is important to emphasize students' development of word knowledge and how teachers help their students learn and use scientific language. We followed two elementary school teachers as they implemented an integrated inquiry-based science and literacy curriculum. This curriculum stresses learning a set of pre-selected key concepts that are important for understanding the scientific idea being taught. Through this approach, our contribution to the field is to describe and provide information about actual science inquiry practices to better understand the sources for promoting conceptual understanding (i.e., understanding of science concepts) through inquiry science. We did this by examining concrete examples of events that are normally taken for granted in classrooms. The call for research on how knowledge is constructed when engaging students in hands-on activities has recurred over the past several decades (e.g., Ritchie and Hampson 1996). Nevertheless, despite the prevalence and importance of science inquiry, few research studies have actually examined teachers' instructional practices in inquiry classrooms (McNeill and Krajcik 2008; Poon et al. 2012), and Crawford (in press, 2014) said that we lack adequate descriptions of the nature of classroom inquiry instruction. Several studies report on students' learning outcome based on written pre- and posttest design. Results are then typically combined with teachers' reports on how science instruction was enacted or by examining the inquiry curriculum (e.g., Minner et al. 2010). Therefore, more in-depth research on the teaching and learning processes within an inquiry-based setting is needed. Since we wanted to contribute to a practice-oriented perspective of inquiry-based science, we observed instructional practices in different phases of science inquiry and the interactions that occurred between teachers and students. This made it possible to illuminate different teaching approaches and how they influenced students' conceptual understanding.

Inquiry Science and Conceptual Learning

A growing body of evidence substantiates inquiry-based instruction as more effective in terms of student learning compared to traditional instruction that focuses on knowledge transmission (e.g., Anderson 2002; Hmelo-Silver et al. 2007; Minner et al. 2010). Teaching strategies that actively engage students in the learning process through scientific investigations are more likely to increase conceptual understanding than strategies that rely on more passive techniques. Inquiry-based instruction has the potential to engage students in active construction of knowledge necessary for understanding as the students seek answers to questions, experience phenomena, share ideas, and develop explanations (Minstrell and van Zee 2000). Minner et al. (2010) reviewed 138 studies on the impact of inquiry science instruction on student outcomes and found a clear positive trend favoring inquiry-based instructional practices. In particular, instruction emphasizing students' active thinking and drawing conclusions from data had a positive effect on the students' development of conceptual knowledge. Likewise, in a study on how teachers' enactment of an inquiry-orientated science curriculum influences student learning, Fogleman et al. (2011) provided evidence of the importance of students actively engaging in inquiry investigations to develop an understanding of key science concepts. The authors emphasized the significant role of teachers when conducting inquiry in the science classroom; in that study, 38 % of the variation in student gain scores occurred between teachers. Despite the substantial support for science inquiry, some ambiguity regarding the positive results exists. Kirchner et al. (2006), for example, presented evidence against the effectiveness of inquiry-based materials and instruction. However, in their study, inquiry was categorized as “minimal guidance during instruction.” In response, Hmelo-Silver et al. (2007) contested this claim, stating that inquiry-based instruction relies on significant scaffolding to guide student learning.

Although inquiry is highlighted in reform documents across the world, and research has shown that inquiry teaching can produce positive results, it does not, by itself, tell teachers exactly how to do it. Science inquiry in the classroom takes on different forms, and there is no one definition. Additionally, few teachers have experience with scientific inquiry, in either their own schooling or training, and thus have very naïve conceptions of inquiry in the classroom (Anderson 2007; Blanchard et al. 2009; Windschitl 2004). Research has also pointed to the influence of teachers’ beliefs about science and science teaching on their receptivity to inquiry-based teaching (e.g., Borko and Putnam 1996; Crawford 2007; Lotter et al. 2007). What teachers know and what they believe shape their interpretations of curricular and instructional approaches. Several studies have suggested that inquiry-based instruction can be supported by research-based curriculum materials (e.g., Davis and Krajcik 2005; Wilson et al. 2010). One such curriculum is from the teaching program *Seeds of Science*, *Roots of Reading* (Seeds/Roots) developed at Lawrence Hall of Science, Berkeley (Cervetti et al. 2006). The Seeds/Roots curriculum consists of a number of units covering life science, physical science, and earth science topics. All units are based on the principle of integrating inquiry-based science and literacy, and the materials are designed to address key science concepts multiple times through multiple modalities (do it, say it, read it, write it) (Cervetti et al. 2006). Considerable evidence supports the efficacy of an integrated curriculum, in terms of both literacy and science outcomes (Cervetti et al. 2012; Guthrie et al. 2004; Magnusson and Palincsar 2004; Yore et al. 2004). A suggested explanation is that when science content is addressed through a combination of inquiry and literacy activities, students learn how to read, write, and talk science simultaneously as these literacy activities support the acquisition of science concepts and inquiry skills (Cervetti et al. 2012; Norris and Phillips 2003). Cervetti et al. (2006, 2012) emphasized the connection between word knowledge and conceptual understanding. They argued that the synergy between science and literacy rests upon the understanding that an active level of word knowledge in science (understanding of words as they are situated within a network of other words and ideas) can be described as conceptual knowledge. We embrace and build on this science/literacy integration, and especially the connection between word knowledge and conceptual knowledge, in the present study.

Research Questions

Most of the evidence that inquiry-based instruction results in significant learning gains, compared to traditional instruction, stems from large-scale experimental studies and studies that include a pre- and posttest for students (Hmelo-Silver et al. 2007; Minner et al. 2010). These studies, however, have not provided insight into the actual teaching and learning process as it occurs moment by moment in the classroom. Our study differs as an in-depth qualitative study aiming to illuminate how teaching approaches foster conceptual understanding in inquiry-based science. Our study provides a detailed view of inquiry-based instruction in elementary school classrooms and uses students’ development of word knowledge as evidence of success. We address this through the following main research questions:

1. How does students’ word knowledge develop throughout different phases of inquiry?
2. How do teachers facilitate conceptual understanding through inquiry-based activities?

Theoretical Perspectives

There are many reasons why students should learn what specific scientific terms mean, including understanding scientific concepts, being able to communicate the ideas and processes of science, and improving their reading comprehension (Bravo et al. 2008; Glen and Dotger 2009; Lemke 1990). It has been well established that learning to use the language of science is fundamental to learning science (Norris and Phillips 2003; Scott et al. 2007; Wellington and Osborne 2001). What is not well-known is how teachers help their students learn and use scientific language. In traditional science instruction, learning new words is sometimes reduced to acquiring definitional knowledge of a large number of words (Cervetti et al. 2006). According to the work of Vygotsky (1986), studying words out of context puts the learning process on the purely verbal plane. Rather than developing students' thinking, this method encourages only reproducing and recollecting established definitions. Many researchers have shown that effective word learning integrates new words in a network of other words and ideas (e.g., Bravo et al. 2008; Stahl and Stahl 2004). As Lemke (1990) put it, "Concepts are just thematic items… we never use them one at a time; their usefulness comes from their connections to one another. So it is really the thematic patterns that we need and use" (p. 91).

Developing Word Knowledge

Knowing a word is not an all-or-nothing phenomenon. It is multifaceted and ranges from having low control of a word (students can decode the term) to passive control of a word (students can provide a synonym or basic definition) to active control of a word (students can situate the word in connection to other words and use the word in oral and written communication) (Bravo et al. 2008; Nagy and Scott 2000). These categories suggest degrees of word knowledge. As active control of words involves understanding words in context and in relation to other words within the discipline, it can be thought of as conceptual knowledge (Bravo et al. 2008) (see Table 1). For example, knowing the science word "force" in an active way means more than being able to recognize the printed word or to recite its definition. Active control approaching conceptual understanding of force involves the ability to understand a word's relationship to other science words, such as "gravity" or "magnetism," and the ability to use the science word appropriately in speech and writing. By treating concepts as equivalent to word meanings, as suggested by Vygotsky (1987), conceptual knowledge develops alongside an increased understanding of word meaning, indicated by the gradient in Table 1. From this perspective, word learning in science should be thought of and taught as concepts that are connected to other concepts to form rich conceptual networks (Cervetti et al. 2006).

Link-Making Strategies

Scott et al. (2011) also emphasized making networks of ideas and concepts to promote conceptual understanding. In an article on pedagogical link-making, they accentuated three link-making strategies for promoting conceptual understanding: (i) support knowledge building, (ii) promote continuity, and (iii) encourage emotional engagement (Table 2). To support knowledge building, everyday and scientific concepts must be linked to integrate (overlap between everyday and scientific ways of explaining) or to differentiate (what it is and what it is not, e.g., force *is not* a real substance) everyday and scientific ways of explaining the concepts. Other knowledge-building links involve linking scientific concepts, creating links to help students see the connections between scientific construction and everyday experiences, and

Table 1 Framework for word knowledge (based on Bravo et al. 2008)

	Level of word knowledge	Cognitive process	Explanation
	Low	Recognition	Knowing how a word sounds or looks when it is written.
	Passive	Definition	Being able to recite a word's definition, but having little understanding of the meaning of the word or its implications.
Conceptual knowledge	Active	Relationship	Knowing the word's relationship to other words and concepts.
		Context	Knowing how to use the word in context. Understanding how the word fits in different sentences.
		Application	Knowing how to apply the word in context when engaging in inquiry about a phenomenon. Linking the word to the empirical data.
		Synthesis	Knowing how to use the word when communicating the emerging knowledge about the phenomena under study. Solving problems in new situations by applying acquired knowledge.

Conceptual knowledge develops alongside an increased level of word knowledge

making links between different modalities of representations (e.g., verbal and graphic). Link-making to promote continuity involves the teacher reviewing events from earlier lessons to develop a scientific story over time that focuses on the substantive content. Since a specific topic is normally taught over time, links should be made between the different sequences to avoid teaching and learning as isolated, disconnected events (Scott et al. 2011). The third link-making strategy, to encourage emotional engagement, differs in nature from the other two, but linking positive engagement to the subject matter is crucial to support the first two. By linking a student's point of view and that student's name, the following discussion brings together perspectives that are identified with different students instead of focusing on anonymous points of view (Scott et al. 2011).

Our theoretical perspectives on teaching for conceptual understanding are based on the development of word meaning and link-making procedures. The frameworks depicted in Tables 1 and 2 are applied as guidelines when we analyze how teachers teach science concepts through inquiry-based activities. Additionally, we included linguistic support in our analysis, denoting how teachers scaffold and encourage students' use of the language of science. This is based on literature that emphasizes that learning to use the language of science is fundamental to learning science (e.g., Lemke 1990; Norris and Phillips 2003; Wellington and Osborne 2001).

Table 2 Link-making strategies to promote conceptual understanding

Link-making strategy	Explanation
Support knowledge building	Making links between different kinds of knowledge. Involves connecting relevant scientific concepts and linking scientific explanations and phenomena
Promote continuity	Making links between teaching and learning events occurring at different points in time. Involves making references to teaching and learning activities across points in time
Encourage emotional engagement	Encouraging a positive emotional response from students by making links to the substantive content of the lessons. Involves making connections between a specific point of view raised by a student and that student's name

Based on Scott et al. (2011)

Methods

In this section, we introduce the context of our study, our data sources, and how these data were collected. We also describe how we selected participants and provide details about our analysis process.

Context of the Study

The study was conducted in Norway as part of a larger ongoing project aiming to test and refine a teaching model that integrates inquiry-based science and literacy, the Budding Science and Literacy project (Ødegaard and Frøyland 2009). The project builds largely on curriculum materials from the Seeds/Roots teaching program. This program introduces the Do-it, Talk-it, Read-it, and Write-it approach, in which students learn science concepts in depth simultaneously as they learn how to read, write, and discuss in an inquiry-based setting (Cervetti et al. 2006). The Budding Science and Literacy project invited elementary school teachers to participate in a year-long professional development course. The participating teachers met once a month for lectures and practice related to integrating inquiry-based science and literacy. The teachers practiced how to use science inquiry as a context for introducing different genres of reading and writing and how to engage students in discussions of evidence related to their investigations. As part of the course, the teachers adapted and implemented teaching materials from the integrated science/literacy curriculum to the local context of their own classrooms (e.g., language, students' age, time and tools available, school policies). Six teachers volunteered to be videotaped while they implemented the teaching materials, and for the present study, we followed two of these teachers. Before we collected data, the participating teachers, parents on behalf of their minor students, and the principals signed an informed consent form agreeing to the videotaping of the classroom instruction for research purposes.

Data Sources

The data were collected from video recordings of the teachers implementing the curriculum. There were four cameras in each classroom: One small wall-mounted camera faced the students, one camera followed the teacher, and two students wore head-mounted cameras. The wall- and head-mounted cameras had satisfactory audio recordings, while the teacher wore a small microphone linked to the teacher camera. This microphone captured all of the teacher talk during the lesson, as well as most of the student talk. Altogether, 35 h of instructional lessons were video recorded, evenly distributed among the six volunteer teachers. The video recordings were coded according to a coding scheme for different modalities (doing, reading, writing, talking) and inquiry activities (see Table 3) developed by the Budding Science and Literacy research group (Ødegaard et al. 2012). The coding scheme for inquiry activities builds on several theoretical frameworks (Bell et al. 2010; Cervetti et al. 2006; Chinn and Malhotra 2002), and was created as an observational tool that describes what was going on in the classroom. We used the coding to get an overview of classroom activities for the project as a whole but do not report on these data in this article. In the present study, we used the overview coding as a resource to select data for further in-depth analysis. The four main categories demonstrating different phases of inquiry are *preparation*, *data*, *discussion*, and *communication*. Each category consists of several codes denoting the activity that takes place

Table 3 Coding scheme for inquiry activities (Ødegaard et al. 2012)

Category	Specific codes
Preparation	Background knowledge/wondering/researchable questions/predict/hypothesis/planning
Data	Collection/registration/analysis
Discussion	Interpretations/inferences/implications/connecting theory and practice
Communication	Orally/in writing/assessing their work

within the category. We do not regard the process of inquiry as rigid, where one step necessarily follows another; the process goes back and forth between the different phases as evidence is collected and ideas are refined. In addition, we used the code *concepts*, which refers to classroom talk that explicitly addresses selected key concepts of the current topic. To get an overview of the data material, we coded the occurrence and duration of each code using Interact software, which allowed us to code the videos directly without transcribing the dialogue (Mangold 2010). There were four coders all together, and interrater reliability for each code was assessed by double coding 20 % of the videotapes. The reliability of the coders was satisfactory (75–80 %).

Selection of Participants

Two of the six volunteer teachers, Anna and Birgit (pseudonyms), were selected for further analysis. To select the participants, we used the initial coding and analyses of the total video material from all six classrooms. Because we wanted to explore science concept instruction, we looked for classrooms coded with the highest frequency of *concepts* (Fig. 1). We also needed to observe an activity in which the students demonstrated possible development in their level of word knowledge after they had engaged with the specific concepts several times. Such development was best achieved during the communication phase, when students were supposed to link their hands-on activity to the scientific content. Thus, we selected Anna and Birgit based on the following criteria: (i) The science concepts are frequently addressed during lessons, and (ii) students communicate their understanding based on a hands-on activity.

For the first criterion, addressing science concepts, Anna and Birgit stood out with higher percentages than the other teachers (as seen in Fig. 1). The second criterion, students communicating their results from an investigation, was realized in only three out of the six classrooms, including Anna's and Birgit's. Therefore, the sources of our analysis were Anna and Birgit.

Anna and Birgit are generalists who teach all subjects. Neither has a formal science background. Anna taught fifth graders (10-year-olds), while Birgit taught fourth graders (9-year-olds). Both teachers created learning environments in their classrooms where students felt safe to ask questions and reveal their ideas. Establishing such norms of behavior is an essential factor of successful learning (Bransford et al. 2000).

Teaching Materials

The Seeds/Roots curriculum comprises several units covering various topics within the different sciences (life science, physical science, and earth science). All the units are based on the principle of integrating inquiry-based science and literacy, and the materials are

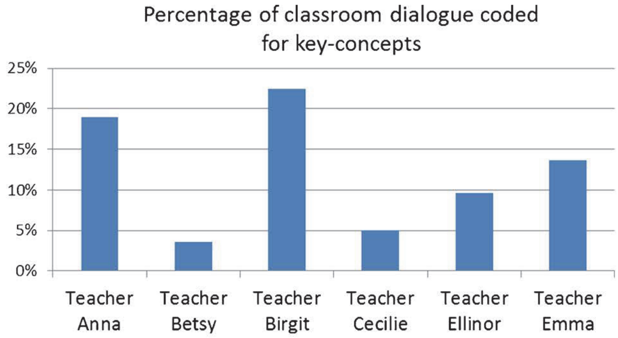

Fig. 1 Results for the first criterion of selecting participants for the study. The figure shows the percentage of coded time for key concepts during classroom dialogue. Teacher Anna, and teacher Birgit, had the highest percentages. All names are pseudonyms

designed to address science key concepts multiple times through multiple modalities (Cervetti et al. 2006). These key concepts consist of words that are central to science and necessary for understanding the scientific ideas (e.g., force, gravity, property, system) and processes (e.g., investigate, data, evidence) taught.

Anna and Birgit taught the introductory sessions from one unit they chose, guided by the detailed step-by-step teacher's guide that came with the unit. Both teachers purposefully and consistently used the materials to guide their enactments. Anna taught the unit *Gravity and Magnetism* to her 10-year-old students. This was the students' first encounter with the topic. It introduced forces as a push or a pull between two objects, and we followed the students' development of word knowledge for *force*. In groups of four, the students investigated examples of forces as either a push or a pull by using two blocks with a hook, a rubber band, and two types of springs (see Fig. 2). The aim of the lesson was to teach what a force is and enable the students to show and explain which forces are at work.

Birgit taught the unit *Digestion and Body Systems* to her 9-year-old students. The students had already been introduced to the concept of *systems* in general. We observed the class learning about the *structure* and *function* of the different parts in a system, with emphasis on the word function. The students worked in groups of four to make a ball-sorting system that separated balls by size. The materials available were a pump, a tube, different types of filters, a collecting bag, and tiny balls in two sizes (see Fig. 3). At the end of the lesson, the students were expected to understand that each part of a system has a function and be able to explain the functions of the different parts in the ball-sorting system.

Analysis

Our aim for this study was to examine students' development of word knowledge and how teachers facilitated students' conceptual understanding during different phases of inquiry. The

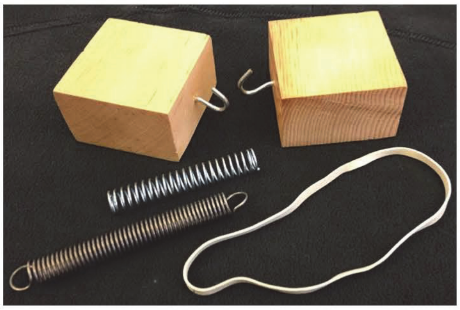

Fig. 2 Materials used in Anna's class included blocks with hooks, two types of springs, and a rubber band

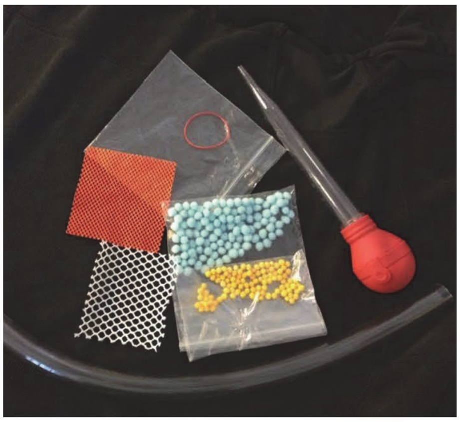

Fig. 3 Materials used in Birgit's class included a pump, a tube, filters, tiny balls, a collecting bag, and a rubber band

phases of inquiry correspond to the categories in the coding scheme: preparation, data, discussion, and communication (see Table 3). For an in-depth analysis, we read and reread transcripts of the classroom discourse from the communication phase. With the research questions in mind, we gradually decided which episodes to concentrate on that would provide us with some answers (Erickson 2012). This process revealed very different results for the two classrooms regarding the students' level of word knowledge. Thus, to explore these results and further our understanding of the interplay between inquiry-based instruction and content, we used the overview coding of the videos to select episodes from the *preparation*, *data*, and *discussion* phases related to the analyzed *communication* phase. We transcribed and analyzed the episodes, which all occurred during a 90-min lesson for both teachers, accordingly. Using the overview coding, we identified episodes that revealed details of how science was presented in the classroom when explored through a micro-analytic lens on the talk between the teacher and students. When lessons are viewed only through checklists or coding schemes built to analyze the macro-structure of the lesson, these insights are not evident (Tan and Wong 2011).

Our analysis concentrated on how the teacher facilitated students learning words as concepts and how she encouraged the students to use the selected key concepts in talking and writing and apply them in context. We analyzed the students' conceptual understanding according to the framework for word knowledge (shown in Table 1), where an active level of word knowledge (being able to apply the word in a context to make meaning) is considered conceptual knowledge (Bravo et al. 2008). When the teachers encouraged and scaffolded the students' use of the language of science, we recorded the action as linguistic support. We also examined the teachers' use of the link-making strategies Scott et al. (2011) emphasized as important for conceptual understanding (Table 2).

Results

Our in-depth analyses of the communication phase in the two classrooms revealed distinct differences in the students' level of word knowledge. Anna's students demonstrated a low level of word knowledge, while Birgit's students demonstrated an active level, consistent with conceptual knowledge. This result baffled us, as both teachers carefully followed the instructions for the integrated curriculum, which emphasizes learning key concepts. To understand why these differences had occurred, we examined the entire sequence of learning activities connected to the student presentations in the two classrooms. This sequence included the preparation before the hands-on activity, the hands-on activity itself, and the discussion that followed the presentations of findings from the hands-on activity. We present the results as they took place in the classroom, organized in Tables 4 and 5 (Anna and Birgit, respectively). In the tables, the results are explained with examples of our coding according to the framework for word knowledge and link-making strategies. After each table, we comment further on the results.

Anna: Rephrasing Students' Answers

In the preparation phase of inquiry, Anna activates the students' prior knowledge by encouraging them to share their thoughts and ideas when they hear the word force. The teacher accepts one-word answers, in which the students' ideas center specifically on muscles, but also on magnets and magic (see Table 4). Connecting force to muscles is a common confusion among students; additionally, in Norwegian, "power," as in muscle power, is identical to the word force. Bravo et al. (2008) emphasized that confusion can be expected when one word holds different meanings depending on the context. However, Anna does not address the students' conceptual confusion. As expected in the introductory stage of a new topic, the students show low control of the word force. However, there is no development in the students' understanding as the teacher wraps up the discussion at the end and moves on to the data collection phase. This phase engages the students in a hands-on activity to collect data by exploring the blocks, springs, and rubber band. Anna circulates as the groups work, and when she asks what kind of force they observe, the students just guess. They are clearly confused about the concept of force, and they are not guided toward understanding how force relates to push and pull. Ole, who responds "shooting force," later contributes during the communication phase, and hangs on to his original idea of force. When the teacher does not address students' everyday perception of a concept and differentiate it from the scientific explanation, the students' initial understanding remains, and their conceptual understanding is not promoted. The students' level of word knowledge for force thus remains low.

During student presentations, none of the groups can explain force as a push or a pull with reference to their hands-on activity. They silently demonstrate push and pull by wrapping the rubber band around the blocks or putting a spring in between the blocks. The students seem to lack the language necessary to explain their investigation, and the teacher takes over and does the talking. When Anna asks questions, she transforms the student responses into the correct phrase she is looking for. Consequently, the meaning of what the students say becomes quite distinct from what the teacher rephrases it into. This is illustrated by Gina's response under *Communication* in Table 4.

In our analysis, the discussion phase had to involve some type of reference to the collected data (Ødegaard et al. 2012). Thus, we selected the discussion that followed the communication phase as an example. After all groups silently demonstrate their work, Anna invites the students to discuss what they have learned. The students continue to refer to muscle power, and mix up push and pull in a way that reveals a lack of understanding of the concept of force. We see that the teacher, when rephrasing the students' answers to include push and pull, makes the necessary links between concepts, while the students are involved only superficially. According to Scott et al. (2011), students' engagement in the link-making process is crucial if scientific conceptual knowledge is the goal. In Anna's classroom, we did not observe strategies that promote continuity and encourage emotional engagement. Based on the students' responses, we saw no development in the students' level of word knowledge for force at this stage. Thus, when Anna concludes that the students have reached the learning goal, it is

Table 4 Examples from Anna's classroom teaching and learning *force* as a concept during the different phases of inquiry

Inquiry phase	Organizational structure	Example	Students' level of word knowledge	Description	Teacher support	Description
Preparation	Whole class	Students refer to *force* as magnetism, magic, and muscles	Recognition Low level	Recognize the word *force* when the teacher asks them what it means	Does not support knowledge building	Accepts one-word answers without encouraging the students to elaborate on their thinking or link the word to a context
		Teacher closes the discussion with a definition of *force*			Does not support knowledge building	Does not address the students' existing ideas of *force* or differentiate between everyday and scientific ways of explaining *force*
Data	Hands-on activity Group work	Anders: We do not know how to make a push	Definition Passive level	Demonstrates an understanding of the word *force* being connected to push		
		Teacher (T): How could you make a push between the two (blocks) if the hooks were not there? (Students put the spring between the blocks and let go. The spring bounces off). And what kind of *force* is that?			Supports knowledge building	Links the word *force* to the students' hands-on experiment
		Anders: Flying Ole: Shooting *force*	Recognition Low level	Recognizes the word *force*, but are not able to relate it to push or pull		
		T: Yes, you push them together			Does not support knowledge building	Provides the answer without guiding the students toward a scientific understanding of *force*

Table 4 (continued)

Inquiry phase	Organizational structure	Example	Students' level of word knowledge	Description	Teacher support	Description
		T: (Turns to the next group) What kind of *force* was that? Push or pull?			Supports knowledge building	Scaffolds to help the students link *force* to push and pull
		Eric: It was a push? (said like a question) Malina: It is a push (pauses) or a pull	Recognition Low level	Recognizes the word *force*, but are not able to relate it to push or pull.		
		T: If you take the blocks like this (takes the blocks with the spring in between) and want to have them closer (walks away)			Does not support knowledge building	Walks away without addressing the students' conceptual confusion
Communication	Group presentation Whole class	Ole: It was shooting *force*.	Recognition Low level	Recognizes the word *force*. Refers to shooting *force*, not demonstrating an understanding of *force* as a push or a pull between two objects		
		T: What kind of *force*?			Does not support knowledge building	Ignores Ole's response and repeats the question. Does not address the group's everyday way of explaining *force*
		Gina: They pull them together	Recognition/definition Passive level	Recognizes the word *force*, approaching definition as she refers to *force* as a pull		
		T: Yes, I pull them apart			Does not support knowledge building	Rephrases the student's response into the "correct" phrase without eliciting the student's thinking or clarifying the change she makes

Table 4 (continued)

Inquiry phase	Organizational structure	Example	Students' level of word knowledge	Description	Teacher support	Description
Discussion	Whole class	Students mainly refer to *force* as muscle power. When asked about push or pull, they continuously mix the two	Recognition/definition Low/passive level	Recognizes the word *force* and can say something about *force* related to push and pull without understanding the meaning		
		The teacher rephrases student responses by inserting or altering their use of push or pull			Does not support knowledge building	Rephrases and links concepts without addressing students' confusion and existing ideas of *force*. Does not explain the difference between everyday and scientific ways of explaining *force*
		The teacher sums up by asking if they all agree on the definition (*force* is a push or a pull between two objects) and puts a star on the board for reaching the learning goal (I can explain what a force is)			Does not support knowledge building	Bases the conclusion on her own link-making of concepts and alteration of students' responses

Each coding for word knowledge and teacher support is justified in the following column labeled description. *Force* is in italics for easy recognition, not because it is emphasized by the speaker based on her own explanations and adjustments of student responses, and not on the students having demonstrated an understanding. This indicates that Anna is focused on the class progressing through the curriculum rather than on addressing the students' needs. Several studies, especially concerning formative assessment, have reported similar findings (Bell and Cowie 2001; Shavelson et al. 2008). The lesson analyzed was the students' first encounter with the concept of force, which might explain, in part, their low level of word knowledge. However, an examination of later lessons revealed that Anna's students remained at a passive level of word knowledge with little or no progress toward conceptual knowledge.

To sum up, Anna is doing the talking and the link-making for the students. She turns their responses into the "correct" phrases and does not encourage or challenge the students to apply the key concepts in a context. Our in-depth analysis reveals that the high percentage coded for *concepts* in the initial overview coding is related to Anna's active role in applying the concepts, not the students' role. The students show a passive level of word knowledge that is inconsistent with conceptual understanding.

We now turn to Birgit's classroom. In Table 5, we present the results from our analysis of the different inquiry phases in her classroom. The table is followed by a thorough description of the results.

Birgit: Students Do the Talking

To activate the students' prior knowledge, Birgit lets them think about and discuss their understanding of the word function in small groups during the preparation phase of inquiry (see Table 5). As the students discuss, Birgit circulates and asks the groups questions before she sums up the discussion for the entire class. The small-group discussion engages all the students in talking, instead of just a few, which is usually the case if the teacher asks the whole class as a group. In this strategy, referred to as think-pair-share, students are given the chance to individually think about a concept before pairing up with a fellow student to discuss their ideas, and finally share these ideas with the whole class. Lyman (1981) introduced the think-pair-share strategy as a way of maximizing participation, focusing attention, engaging students, and giving them time to think about the concepts presented. Birgit is attentive to the student discussions and scaffolds the students' learning by linking the word function to the students' everyday experiences. She keeps challenging the students with follow-up questions and builds on the students' responses to guide the students toward a more sophisticated understanding of the word function. When the groups start to put the different parts together to build a ball-sorting system, Birgit observes the groups closely. She asks them to explain what they are doing and supports them as they develop their vocabulary. During the activity, Birgit encourages the students to discuss why their system worked as intended, directing their thinking toward the function of the different parts. The students apply the meaning of function in context and link the meaning to their empirical investigation. Additionally, when Birgit requires the students to review the inquiry process, she facilitates link-making between what they experienced in the process and their content knowledge.

During the communication phase, Birgit encourages the students to name the parts and describe the function of each part. This encouragement makes the students aware of the words they use, and they improve their performance. The students do the talking, and the teacher scaffolds their presentation, urging the students to express their understanding. We observe that the students link the scientific concept of function to an everyday way of explaining, and they combine different forms of representation when using their ball-sorting system as support when the students present their findings orally. Involving students in creating such links is

Table 5 Examples from Birgit's classroom teaching and learning *function* as a concept during the different phases of inquiry

Inquiry phase	Organizational structure	Example	Students' level of word knowledge	Description	Teacher support	Description
Preparation	Group work	Teacher (T): What do you think the word *function* means, Mary?			Supports knowledge building	Encourages the students to provide an everyday meaning for the word *function*
		Mary: How something works	Definition Passive level	Knows the definition of the word		
		T: Mm. Do you have any examples? Mary: A car or a guitar			Supports knowledge building	Makes the student link the word *function* to something familiar
		T: Yes, and how does that *function*? Talk about Mary's example in the group			Supports knowledge building Encourages emotional engagement	Encourages students to link *function* to everyday concepts and phenomena. Acknowledges and builds on Mary's contribution
Data	Hands-on activity Group work	T: Does your system work?			Supports knowledge building	Directs students' thoughts to everyday words for *function* and links it to the concept of system
		Peter: Yes, this one here (points) T: (Interrupts) what do you mean by "this one"?			Linguistic support	Makes the student name the parts
		Peter: The rubber band is wrapped around to hold the filter, and we put the pump here to blow air	Application Active level	Applies the meaning of the word in context and links it to the investigation		
		T: What is the air doing?			Supports knowledge building	Prompts the student to be more specific about *function*, uses everyday language
		P: The air makes the ball move further down the tube	Application Active level	Applies the meaning of the word in context and links it to the investigation		

Table 5 (continued)

Inquiry phase	Organizational structure	Example	Students' level of word knowledge	Description	Teacher support	Description
		T: Ok, good. Now, talk together in the group about what it was that made the system work as intended			Supports knowledge building	Encourages the students to review the inquiry process, thus facilitating link-making between their own experiences and content knowledge
Communication	Group presentation Whole class	T: Good, you made it work. Now I want you to explain it once more, and this time say the name of each part, like filter, tube, pump, and try to explain the *function* of each part, how it works			Provides linguistic support. Supports knowledge building	Scaffolds students' use of the language of science by indicating words they should use and making them articulate the words. Encourages students to link concepts through explaining each part's *function*
		(A student in the group explains the system, naming each part by its name) T: Can you also tell us something about the function of the different parts?			Supports knowledge building	Encourages students to link concepts through linking *function* to the different parts of the system
		Emily: The filter separates the balls. We used the white filter instead of the orange one, because the white one has bigger holes, so the small balls can pass, but not the big ones (pointing at the system as she explains)	Application Active level	Applies the meaning of the word in context and links it to the investigation. Links different forms of representation		

Table 5 (continued)

Inquiry phase	Organizational structure	Example	Students' level of word knowledge	Description	Teacher support	Description
Discussion	Group work and whole class	Based on their investigations, the students discuss, first in pairs and then in whole class, the *function* of each part. The teacher provides an example (the *function* of the plastic bag is to collect the balls). She also asks the students to consider the shape and structure of each part, and its relevance to the part's *function*. The lesson ends with a discussion of the *function* of pumps the students know in everyday life			Provides linguistic support Supports knowledge building	Demonstrates how to phrase a sentence containing the necessary information Links students' experiences to content knowledge, links science concepts (e.g., *function* and structure), links scientific explanations to everyday experiences
		Students use the sentence the teacher modeled to talk about each part's *function*. They especially discuss that the soft and squeezable structure of the pump is necessary for blowing air. The teacher directs the discussion of other pumps toward a heart that pumps blood	Synthesis Active level	Knows how to apply the word in context and how to use acquired knowledge in new situations	Promotes continuity	Links what they have learned to following sessions that involve the circulatory system

Each coding for word knowledge and teacher support is justified in the following column labeled description. *Function* is in italics for easy recognition, not because it is emphasized by the speaker what Scott et al. (2011) deem necessary for learning scientific conceptual knowledge. After the presentations, an extended discussion takes place in the classroom. Birgit encourages the students to apply the word function in their talk and models a sentence. She continues to use the think-pair-share strategy familiar to the students to engage and involve them in the discussion, jumping directly to the pair-up and start-talking part without an individual thinking part first. The students are now able to apply the word function in context and in relation to other words and concepts, and the students' level of word knowledge is consistent with conceptual knowledge. When the teacher guides the students toward talking about the example of a heart as a pump at the end of the discussion, she links what they have learned to following sessions that involve the circulatory system. Thus, she promotes continuity, one of the strategies recommended in the link-making framework based on the work of Scott et al. (2011). In addition, in this example, the teacher links scientific explanations to everyday experiences. We observed that in this classroom, moving on depends primarily on the students' level of understanding, not the curriculum.

Summing up Birgit's classroom, we see that the students are active participants, doing most of the talking with the teacher closely scaffolding their learning progress. Birgit frequently engages students in the think-pair-share strategy, and requires them to use the new science words in their talk. Several link-making strategies are at work, and Birgit makes the link available for the students so that they can come to understand the links for themselves as they discuss their ideas. She makes the students apply their new knowledge in context when engaging in the different phases of inquiry, and the students demonstrate word knowledge consistent with conceptual understanding.

Comparing the students in the two classes learning different key concepts (*force* versus *function*) might seem to give an unfair image of the results. The key concepts are different, and one class (Birgit's) had already worked with related concepts in earlier lessons. However, even though both teachers are dedicated to teaching science and motivating their students, the teachers demonstrate, as described, different teaching approaches. Our results indicate that Anna's teaching approach, even after instruction on the same topic over time, does not result in her students reaching a conceptual understanding of *force*. Birgit's approach, however, seems to be more successful.

Discussion

Students' Development of Word Knowledge

In this study, we closely observed two teachers and their interactions with students through different phases of inquiry and focused on teaching and learning science key concepts. In relation to our first research question regarding students' development of word knowledge toward conceptual knowledge, we see distinct differences between the students in the two classrooms. Anna's students never transcend a passive level of word knowledge, while Birgit's students demonstrate word knowledge approaching conceptual understanding in the initial phase of inquiry. In Anna's classroom, the students mainly provide short sentences and one-word answers. The students are not scaffolded linguistically or sufficiently encouraged to talk science, which has been well established as necessary to learn science (e.g., Lemke 1990; Wellington and Osborne 2001). When students are not doing the talking, it becomes challenging for Anna to assess the students' level of understanding and subsequently adapt her teaching according to the students' need, which several authors have emphasized as essential for promoting student learning (e.g., Black and William 1998; Harlen 2003; Shavelson et al.

2008). Birgit's students, however, develop their level of word knowledge toward conceptual knowledge in accordance with the framework for word knowledge (Bravo et al. 2008) through hands-on and talking activities as the students actively apply the word function in new and familiar contexts. These findings support the approach of the implemented curriculum of developing conceptual knowledge by treating words as concepts (Cervetti et al. 2006), as well as the suggestion of Scott et al. (2011) that link-making between different kinds of knowledge helps construct conceptual understanding.

Anna's students remain at a low level of word knowledge over time, which indicates that inquiry by itself, even when essential consolidating phases such as discussion and communication are realized, does not foster conceptual understanding. Our results suggest that for students to develop word knowledge toward conceptual knowledge, teachers must encourage and scaffold students' use of the language of science through all the phases of inquiry. Teachers must emphasize the use of necessary science words and concepts so students can discuss and communicate their growing understanding of a scientific idea. Thus, for students to develop word knowledge toward conceptual understanding, the theoretical frameworks applied (word knowledge and link-making) are effective only if the students are doing the talking.

Teaching Approaches

The teachers' pedagogical approaches are the subject of our second research question. The teachers' methods of interacting with the students during the inquiry activities are quite distinct; thus, we distinguish between and discuss the teachers' main approaches.

Anna starts the lesson by mapping her students' existing ideas of the word force, an activity in accordance with the curriculum's intention of fostering conceptual knowledge through the development of students' level of word knowledge (Bravo et al. 2008). However, she never addresses the students' lack of understanding of the word force. According to Scott et al. (2011), link-making strategies that support knowledge building include differentiating between everyday and scientific ways of explaining. This implies that it is not sufficient to teach what force is; it is equally important to understand what it *is not*. Consequently, since Anna never refers to the divergence between the students' understanding of the concept of force and the view of established science, not surprisingly, the same conceptual confusion appears throughout all phases of inquiry. This finding supports Myhill and Brackley's (2004) findings that teachers made very little use of students' prior knowledge and there was almost no evidence that the teachers recognize the impact of prior knowledge on conceptual development. An inquiry-based approach to teaching and learning consists of several phases comprising many different activities. If teachers do not make links to promote continuity between the different phases and activities as suggested in the link-making strategies of Scott et al. (2011), then conceptual learning is unlikely to occur. For instance, mapping students' existing ideas is of little use if these ideas are not acknowledged and set as a starting point for the activities that follow.

In Anna's classroom, the teacher does most of the talking, a typical strategy in schools (e.g., Mercer et al. 2009). Nevertheless, to develop conceptual knowledge, students need to learn the language of science, which requires practice, not just listening (Lemke 1990; Mercer et al. 2009). Science inquiry provides ample opportunities for students to engage in talking activities. For instance, Birgit consistently involves her students in a think-pair-share activity that allows all of them to talk science (illustrated under *Discussion* in Table 5). In this activity, students discuss their ideas and findings in the different phases of inquiry. The students practice the language necessary to communicate their ideas while using the acquired key concepts to further their conceptual understanding. This offers a practice-oriented example of how to use the synergies of an integrated science and literacy approach, an approach that supports learning of both science and literacy as advocated by several researchers (e.g., Cervetti et al. 2012; Norris and Phillips 2003; Yore et al. 2004). Students' involvement in science creates opportunities for practicing literacy activities that require knowledge of science concepts. Furthermore, instruction emphasizing students' active thinking during inquiry has been reported in many other studies as essential for fostering conceptual knowledge (e.g., Fogleman et al. 2011; Minner et al. 2010). Based on our findings, we see the need to use strategies like think-pair-share to actively involve students in talking and thinking to learn the key concepts of the scientific idea presented. This strategy provides an opportunity for the students to talk science, which, as we saw from the results for our first research question, is critical for students to develop conceptual knowledge.

Birgit urges her students to use the language of science, providing linguistic scaffolding and setting a standard for the classroom discourse. Immediately, she introduces the word function as a concept and connects it to students' everyday language and perceptions. This exemplifies teaching conceptual knowledge through thinking of words as concepts (Bravo et al. 2008) and linking science concepts to students' prior knowledge (Scott et al. 2011). When the students discuss and communicate their inquiry results, they use the word function spontaneously. Thus, the inquiry task created the need for the students to use the concept of function to explain their outcomes. Likewise, Birgit, through her teaching approach, provides the students with a useful scientific vocabulary. This constant focus on the students doing the talking, forcing them to include new science words in their existing vocabulary, is crucial for promoting fluency in the language of science, and for promoting students' development of conceptual understanding. Hmelo-Silver and Barrows (2006) described similar findings: pushing students to explain their thinking and helping the students articulate their ideas supports them in their sense-making process. In contrast, Anna does not focus much on linguistic scaffolding to support the students' learning process. Even though Anna actively engages her students in all inquiry phases, they are at no point required to link or apply the key concepts emphasized in the teaching materials. Consequently, her students lack the vocabulary necessary to communicate their results, and her students' level of word knowledge does not develop toward conceptual knowledge as described in the framework for word knowledge (Bravo et al. 2008). This finding is in line with Furtak and Alonzo's (2010) finding regarding elementary school teachers implementation of an inquiry-based unit: Teachers tend to prioritize activity over understanding when they teach inquiry-based science. Our results emphasize the need for teachers to make students active participants throughout all phases of inquiry by constantly focusing on students practicing to use the language of science.

Anna often takes bits and pieces of the students' responses and turns them into the "correct" phrase without actually considering the students' answers. O'Connor and Micheals (1996) argued that this type of revoicing, rephrasing student responses to "fit" the correct answer, does not support student learning. Even so, Anna opens the discussions for student participation and encourages them to contribute their ideas, especially during the preparation phase. According to Mortimer and Scott's (2003) communicative approach, such dialogic discourse is essential for promoting conceptual understanding. They also emphasize that learning is enhanced by balancing dialogic and authoritative approaches, in which the teacher focuses on factual statements. Thus, Anna follows the suggested pattern of talk. However, when she moves from the dialogic to the authoritative discourse, and concludes with shared knowledge, the students are not sufficiently included, and their existing everyday perceptions of force remain intact. This indicates an emphasis toward the "correct" answer instead of paying attention to the students' understanding of the concept. To support conceptual understanding, a teacher must be explicit about the relation between students' ideas and the established scientific view of the topic the teacher is teaching. This is advocated by Scott et al. (2011) as a link-making strategy that needs to be addressed in science classrooms to promote learning. However, if the teacher does not understand what the student is suggesting, or is unable to link it to the current task, incorporating the students' contributions effectively will be very difficult. Elementary school teachers' lack of science content knowledge and pedagogical content knowledge has been well documented (e.g., Harlen and Holroyd 1997; Kind 2009; Magnusson et al. 1999). Thus, a low level of content knowledge might be one explanation for why a teacher adjusts students' responses toward "one right answer" without providing any further explanation. Another possible reason, in Anna's case, is that concluding with one answer seems to be the norm; consequently, this will shape her instructional approach, as shown in the research on teacher beliefs (e.g., Crawford 2007; Lotter et al. 2007).

We consider this finding about the teacher following a renowned instructional strategy, like Mortimer and Scott's (2003) communicative approach, with a different outcome than assumed, as yet another example of the importance of in-depth classroom analyses. However, more research is needed to provide teachers with practice-oriented examples of how to effectively implement pedagogical approaches in a way that fosters conceptual learning, both in general and especially through inquiry. Additionally, teacher educators and professional development courses must emphasize the importance of students doing the talking when teachers introduce pedagogical strategies that are expected to support knowledge building.

Limitations

Even though the results of this study are limited by the teachers teaching different units, we believe that the differences in the results are not linked to the specific units. We consider the differences a matter of teaching approach, regardless of the topic, since the units share the same underlying principle of engaging students in different activities to learn science concepts in depth. A second limitation of this research is related to the small sample; thus, the findings are illustrative and not intended to be representative or generalizable. Nevertheless, the results offer insight that can add to the knowledge about teaching inquiry-based science lessons and fostering conceptual learning.

Conclusion

In this study, we provided examples of how to develop students' level of word knowledge toward conceptual knowledge in an inquiry-based setting. The study is not intended as a criticism of the teachers' practice, but as a way to highlight aspects of inquiry-based science and conceptual learning that were not apparent to us or to the participating teachers before we examined the classroom interactions. The in-depth analyses revealed aspects of different teaching approaches that necessitated attention. Our results suggest that conceptual learning occurs when students are required to apply key concepts in their talk throughout all phases of inquiry, with the teacher closely scaffolding the students' use of language. In contrast, conceptual understanding is not promoted when teachers do the talking, rephrase students' responses into the correct answer, or fail to address students' everyday perceptions of scientific phenomena. The frameworks applied for word knowledge and link-making are effective in terms of student conceptual learning only if the students are the ones doing the talking and the ones actively engaged in making the links. Furthermore, the results reveal that the two teachers in our study used the potential of the curriculum materials in different ways, supporting the findings of Fogleman et al. (2011) that teachers are responsible for a significant amount of the variation in student learning. Curriculum materials are important, but not sufficient for all teachers to enhance inquiry instruction. If the teacher does not know how to use the curriculum materials to their full potential, his or her students are concurrently not provided with the best opportunities for learning. For science learning to occur in the classroom, a central task for teacher educators and teacher training is to emphasize the importance of connecting the different phases of inquiry instead of treating activities within each phase as isolated events. Moreover, when pedagogical strategies are introduced for pre- and in-service teachers, the significance of encouraging and pushing students to talk science, as well as how to scaffold students' development of word knowledge toward conceptual knowledge, must be stressed. This study offers insight into students' development of conceptual understanding through inquiry, yet at the same time the findings generate additional questions that require a revisit to our video recordings. Some of these questions are as follows: How do students apply the key concepts when they talk in groups during different inquiry activities, and what type of teacher interference connected to these discussions promotes learning? Our results also inform our larger project and help refine a teaching model that integrates inquiry-based science and literacy. The importance of encouraging and pushing students to talk science are included as a central aspect of the teaching model being developed, which will be applied in teacher training for pre- and in-service teachers.

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Inquiry-Based Science: Turning Teachable Moments into Learnable Moments

Berit S. Haug

Abstract This study examines how an inquiry-based approach to teaching and learning creates teachable moments that can foster conceptual understanding in students, and how teachers capitalize upon these moments. Six elementary school teachers were videotaped as they implemented an integrated inquiry-based science and literacy curriculum in their classrooms. In this curriculum, science inquiry implies that students search for evidence in order to make and revise explanations based on the evidence found and through critical and logical thinking. Furthermore, the curriculum material is designed to address science key concepts multiple times through multiple modalities (do it, say it, read it, write it). Two types of teachable moments were identified: planned and spontaneous. Results suggest that the consolidation phases of inquiry, when students reinforce new knowledge and connect their empirical findings to theory, can be considered as planned teachable moments. These are phases of inquiry during which the teacher should expect, and be prepared for, student utterances that create opportunities to further student learning. Spontaneous teachable moments are instances when the teacher must choose to either follow the pace of the curriculum or adapt to the students' need. One implication of the study is that more teacher support is required in terms of how to plan for and effectively utilize the consolidation phases of inquiry.

Keywords Inquiry · Conceptual learning · Teachable moments · Video-based classroom study

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B. S. Haug
The Norwegian Centre for Science Education, University of Oslo, P.O. Box 1106, Blindern, 0317 Oslo, Norway
e-mail: b.s.haug@naturfagsenteret.no

Introduction

A major challenge in science education is how to support teachers in understanding and enacting inquiry-based instruction. Although research supports inquiry-based science instruction as more effective in terms of student learning compared to instruction focusing on knowledge transmission (e.g., Anderson, 2002; Hmelo- Silver, Duncan, & Chinn, 2007; Minner, Levy, & Century, 2010), an inquiry-based approached does not in itself entail detailed teaching instructions. Science inquiry in classrooms takes on different forms, and there is no one definition of what it is. Around the world, policy documents and curriculum materials are developed based on the idea of inquiry-based instruction as the way to improve science education (Abd-El-Khalick et al., 2004; Rocard, 2007). However, research indicates that actual implementation of science inquiry in school is problematic (Abd-El-Khalick et al., 2004; Ireland, Watters, Brownlee, & Lupton, 2012), and that teachers have not fully applied inquiry-based science in their classrooms (Asay & Orgill, 2010; Crawford, 2000; Windschitl, 2003). Furthermore, few research studies have explicitly examined teachers' instructional practices in inquiry-based classrooms (McNeill & Krajcik, 2008). Thus, concrete examples are required to better understand how inquiry science is enacted in the classroom in ways that foster student learning. Science inquiry in the present study involves students searching for evidence in order to make and revise explanations based on the evidence found and through critical and logical thinking (Barber, 2009).

With this study, the contribution to the field was to observe inquiry-based classroom instruction and examine how this approach to teaching and learning can facilitate students' conceptual understanding (i.e., understanding of science concepts). More specifically, the study aims to identify teachable moments and examine how teachers respond to these. A teachable moment provides opportunities to further student learning and includes the time during which learning a particular topic or idea becomes possible or easiest (e.g., DeWitt, 2012; Hyun & Marshall, 2003). Although some refer to a teachable moment as an unplanned opportunity for learning that occurs and passes in a split second, this may very well be a planned event (Glaswell & Parr, 2009). While teachable moments provide opportunities for learning, learnable moments in this study refer to episodes during which students actually are helped toward conceptual knowledge. Whether teachers capitalize upon teachable moments and turn them into learnable moments is manifested in the interaction between student and teacher and in teachers' action to student responses.

Learning Science Through an Inquiry-Based Approach

As mentioned, there is no specific definition of what inquiry is or agreement on how to explicitly engage students in inquiry-based science in ways that enhance student conceptual understanding. What is collectively agreed upon is that inquiry-based instruction involves students pursuing answers to a researchable question and comparing their answer with what scientists already know about the world (e.g., Cervetti, Pearson, Bravo, & Barber, 2006; Crawford, 2007). Data can be collected through firsthand investigations (hands-on) and secondhand investigation (consulting text to learn of others' interpretations. (Palincsar & Magnusson, 2001). Inquiry can be thought of as a set of interrelated processes, or activities, often referred to as cycles of inquiry (e.g., Cervetti et al., 2006; Chinn & Malhotra, 2002; Hapgood, Magnusson, & Palincsar, 2004). Ødegaard, Mork, Haug and Sørvik (2012) build on these theoretical perspectives when creating four main categories demonstrating different phases of inquiry: preparation (e.g., prior knowledge, researchable question, prediction, design), data (collect and analyze data), discussion (e.g., discuss empirical evidence, connect theory and practice), and communication (communicate and justify results). Findings from several studies highlight the importance of the communication and discussion phases of inquiry to foster conceptual understanding in students (e.g., Asay & Orgill, 2010; Minner et al., 2010). These are consolidation phases in which students present and discuss their empirical findings and with the teacher's help connect their results to theory and reinforce new knowledge. In Minner et al.'s (2010) review of 138 studies on the impact of inquiry science instruction on student outcomes, instruction that emphasizes student active thinking and drawing conclusions from data shows a positive effect on students' development of conceptual knowledge. Likewise, Asay and Orgill (2010) stressed the importance of the communication phase for learning to take place. They state that to develop understanding of scientific concepts, students must explain and justify their conclusions instead of just presenting their findings as collected evidence. Similarly, Bigozzi et al. (2002) considered the ability to justify data the most evident feature that distinguishes deep and lasting learning from learning that is purely oral and superficial. However, a study by Ødegaard et al. (under review) examining teachers' enactment of an integrated inquiry-based science and literacy curriculum demonstrated that teachers spend less time in the consolidation phases than suggested by the curriculum. To develop conceptual knowledge students need help to link scientific concepts to their everyday experiences, to link new and familiar science words and concepts, and learn how to use concepts in context (Bravo, Cervetti, Hiebert, & Pearson, 2008; Scott, Mortimer, & Ametller, 2011). Asay and Orgill (2010) found few references to students connecting their findings with what is scientifically accepted when the researchers reviewed articles published by in-service teachers. If such connections were made, the teacher was the one who told the students what the connections were or what they should be. These results may indicate, as has been seen in previous studies (e.g., Kang, Orgill, & Crippen, 2008; Ruiz-Primo & Furtak, 2007), that teachers focus more on the hands-on aspects of inquiry than on the sense- making aspects. Teachers view inquiry more as a process about which students should learn and in which students should participate than as a vehicle for learning science content (Asay & Orgill, 2010). Therefore, how to teach for conceptual understanding through inquiry needs to be further explored, and teachers should be provided with examples from the classroom for how to capitalize upon teachable moments that occur, especially during the consolidation phases of inquiry.

Critical Moments

Myhill and Warren (2005) refer to the points during instruction when an opportunity arises for the teacher to scaffold student understanding as critical moments in classroom interaction. They defined a critical moment as a discourse unit in which the teacher's utterance is significant either in supporting the development of a student's understanding or in hindering it, or when an opportunity to build on a student's response was missed (p. 59). In a classroom study of how teachers use talk to scaffold student learning, Myhill and Warren (2005) identified three types of critical moments: those that caused confusion for learners, those that steered the discourse heavily along a predetermined path, and those that were responsive to student learning needs (p. 60). Critical moments that created confusion in learning occurred because of the teacher's insecurity regarding his or her own subject knowledge or as a result of poor recognition of the impact of students' prior knowledge, understanding, or experience. Those categorized as steering the discourse along a predetermined path occurred when the teacher ignored or dismissed responses from students, cued the students to a predetermined answer, or redirected students' responses to the teacher's agenda. The third type of critical moments, those that were responsive to student learning, occurred when the teacher responded flexibly to the students' responses or created more opportunities for students to interact with each other and become involved. The first two types, moments creating confusion in learning and heavily steering the discourse, were more common in classrooms than the last type that demands more flexibility of the teacher and sometimes deviates from the planned task and teaching objectives. Myhill and Warren (2005) primarily referred to critical moments as spontaneous unplanned opportunities created by a student utterance. Critical moments are comparable to this study's depiction of teachable moments, however, as put forward by (Glaswell & Parr, 2009), teachable moments emerge in different ways and are created by different constituents. In the present study, Myhill and Warren's (2005) critical moments were applied as guidelines when searching for teachable moments and examining how teachers respond to these—without the limitation of being spontaneously occurring incidents created by student responses.

Research Questions

This study of inquiry-based science instruction sought to identify teachable moments that provide opportunities to foster conceptual learning in students. Furthermore, this study examined how teachers capitalize upon these opportunities and turn them into learnable moments. This was carried out through the following research questions:

- What is the nature of the teachable moments observed?
- How do teachers utilize these teachable moments to support student learning?

Methods

This section introduces the context of the study, provides background information on the participating teachers, and then describes how data were collected, selected, and analyzed.

Context of the Study

The study took place in Norway and was part of a larger project, the Budding Science and Literacy project. In this project, teachers and researchers collaborated to test and refine a teaching model that integrates inquiry-based science and literacy. The integrated science and literacy approach builds largely on the teaching program Seeds of Science/Roots of Reading (Seeds/Roots), in which students learn science concepts in depth simultaneously as they are taught how to read, write, and discuss through inquiry-based science (Cervetti et al., 2006). In Seeds/Roots, science inquiry involves students searching for evidence to support their ideas through firsthand (hands-on) and secondhand (text) investigations. Students also engage in critical and logical thinking to learn how to make and revise explanations based on the evidence found (Barber, 2009). The Budding Science and Literacy project invited elementary school teachers to participate in a professional development course focusing on integrating inquiry-based science and literacy through the do it, talk it, read it, and write it approach. As part of the course, the teachers adapted and implemented curriculum materials from Seeds/Roots to the local context of their classrooms (e.g., language, students' age, time and tools available, school policies). The Seeds/Roots materials consist of a number of units covering several topics within the different sciences (life science, physical science, earth science) (Cervetti et al., 2006). With every unit comes a detailed step-by-step teacher's guide describing when to introduce, and how to combine, the different modes of learning (do-talk-read-write). Also included are in- depth science background, instructional suggestions, and statements of what students should master at specific points in the unit, for example, knowing how the targeted scientific concepts interrelate to make meaning. Six teachers volunteered to be videotaped during the implementation. Before the data were collected the participating teachers, parents on behalf of the under aged students, and the principals signed an informed consent form agreeing to use the video recordings for research purposes.

Participants

The six participating teachers (Table 1) attended a year-long professional development course with monthly meetings. As part of the course, the teachers implemented a number of sessions from a Seeds/Roots unit of their choice to teach in their classroom. None of the teachers had formal science background; they were generalists who taught all subjects in elementary school (6–12 years old). The typical participant attended the course with one or several colleagues from the same school, as intended by the course developers to create opportunities for the teachers to co-operate locally. Years of teaching experience varied among the teachers, from a novice, who was in her second year of teaching, to experienced teachers with more than 20 years of practice.

Data Sources

Data were collected from video recordings of the curriculum implementation. There were four cameras in each classroom: One small wall-mounted camera faced the students, one camera followed the teacher, and two students wore head-mounted cameras.

Table 1. Background information of the participating teachers

Teacher	Grade (age)	Number of students	Years of teaching experience
Anna	5 (10–11)	14	0–5
Betsy	1 (6–7)	18	11–15
Birgit	4 (9–10)	24	11–15
Cecilia	3 (8–9)	19	20+
Ellinor	3 (8–9)	16	11–15
Emma	3 (8–9)	21	20+

All names are pseudonyms

The wall- and head- mounted cameras had satisfactory audio recordings, while the teacher wore a small microphone that was linked to the teacher camera. This captured all teacher talk during the lesson, as well as most student talk. Altogether, 35 h of instructional lessons were video recorded, evenly distributed among the six teachers who volunteered for the study.

Analyses

The objectives of the analyses were to identify teachable moments during inquiry and examine how these were capitalized upon by the participating teachers to support student conceptual learning. Several studies have emphasized that for inquiry-based science to be effective in terms of conceptual learning, students need to draw conclusions from data and compare their empirical findings to existing theory (e.g., Asay & Orgill, 2010; Crawford, 2007; Minner et al., 2010). Thus, a starting point for the analysis was to locate events in the video material signifying a discourse based on students' first- or secondhand investigations. Normally, this would be in a phase of inquiry where students discuss their empirical findings, a communication phase where students present their findings, or a summing-up situation. When searching for such events to identify teachable moments, the detailed step-by-step descriptions in the teacher's guides that followed the curriculum materials were used as support. Selecting episodes based on supplementary resources is a method suggested by Derry et al. (2010) to reduce the workload of going through countless hours of video. After scanning the teacher's guide for discussion and communication phases, the corresponding events in the video material were located. Among these events, episodes involving a situation that provided a platform to enhance students' conceptual understanding were selected as teachable moments. Further analysis involved identifying how the participating teachers utilized the selected teachable moments to enhance student learning. For this purpose, episodes were selected based on several criteria: the presence of a teacher-student interaction; student understanding was manifested in their verbal expressions, and; Myhill and Warren's (2005) definition of a critical moment: "a discourse unit where the teacher's utterance is significant either in supporting the development of a child's understanding or in hindering it" (p. 59). Five teaching sequences were eventually considered representative and significant to inform the study. To help explain and understand how the teachers utilized the moments identified in the video, the selected sequences were analyzed according to Myhill and Warren's (2005) three types of critical moments. Additionally, students' conceptual understanding was assessed based on how students linked science words and concepts and used them in context (Bravo et al., 2008; Scott et al., 2011).

Limitation of the Study Design

A limitation of the study design involves using video as an only source of data. Triangulation of sources, for example in this case to include teacher interviews where teachers explain their actions, would have contributed to shed light on the phenomena examined (Erickson, 2006). However, since this study is part of a larger project, the timespan between video recordings and subsequent analysis for this specific study was more than a year. Thus, even if it had been possible to revisit the teachers and get their comments on the selected episodes in retrospect, I believe the contribution from the teachers would have been limited in terms of explaining their actions. As Derry et al.

(2010) point out, it is preferable to obtain participant involvement as soon as possible after recording the video.

Results

Analysis of the data revealed two qualitative different ways in which teachable moment occurred: planned and spontaneous. Within both categories, there were examples of opportunities capitalized upon as well as missed. The first category is denoted planned teachable moments. As the teachers were following a detailed teacher's guide, inquiry activities that are considered central to foster conceptual understanding in students, like communicating findings and discussing evidence to make and revise explanations, were interwoven in the curriculum materials. The teacher's guides also offered recommendations for what to include in these activities (e.g., help students connect the concepts they have been working on). In these phases of the inquiry, when students have been introduced to the unit's key concepts through different modes of learning (reading, writing, talking and/or doing), teachers should typically expect incidents in which student utterances can be built on or reveal a need for clarification and further explanations. Thus, these events that were initially orchestrated for consolidating knowledge were categorized as planned. Within these events, sometimes an utterance made by the teacher or a student brought the discourse in a different direction than described in the teacher's guide. If these utterances created an opportunity to further the students' understanding of the topic, they were labeled spontaneous teachable moments. There were more planned episodes than spontaneous ones in the data set, which was expected since the data was collected from phases of inquiry that were designed to reinforce knowledge based on shared experiences among the students. Thus, the teacher should anticipate and be prepared to act on student questions or responses connected to these experiences. Results are presented by category, first planned and then spontaneously occurring teachable moments, and include examples of episodes that illustrate teachable moments that were capitalized upon or missed.

Planned Teachable Moments, Missed

Episode 1

The first example of a missed planned teachable moment is from Cecilia's third- grade classroom. They explored the unit Variation and Adaptation, and science key concepts for this unit included characteristics, variation, and adaptation. In the selected episode, the teacher invited students to discuss what they had learned after sitting in small groups looking for characteristics and variation in six different birds depicted on cards. This was the third session of the unit, and the teacher's guide states that at this point students should be able to describe multiple examples of differences and similarities between organisms and link this to where they live and what they eat.

> Teacher Cecilia (T): What differences did you see, or observe?
> Nina: This one has a long and pointy beak, and this one doesn't have such a pointy beak.
> T: Mm. Hanna.
> Hanna: In this one, the beak is pointing down.
> T: Yes, do you know why it has a beak like that?

> Hanna: No.
> T: No. Does anyone know? Were you going to say something, Tomas? (A student in the background says: It eats fish.)
> Tomas: Because it can capture predators.
> T: Or it is a predator, it captures other animals. That is why it has a beak like that. Emma.
> Emma: One is big, and one is small.
> T: Yes, different sizes. Dan.
> Dan: This is an eagle and this one…
> T: This one with the red breast?
> Dan: Yes. It's that this one is bigger and this one is smaller, and this one eats like …worms, and beetles ….and this one eats birds.
> T: Yes. You think it looks like that because of the beak? Yes. Ella.
> Ella: Different shapes.
> T: Yes. Different shapes.
> The dialogue continues with students identifying different colors, sizes, and shapes.

This is considered a planned teachable situation since it is a sequence in which students were expected to demonstrate their understanding of how to link the selected key concepts in a context to make meaning. When students are engaged in activities that reveal the students' thinking, the teacher has an opportunity to assess student reasoning and adapt his or her teaching according to the students' needs. In the selected excerpt, there are two missed opportunities to act upon students' responses. First, Tomas, prompted by another student, seems to link the bird's beak to what the bird eats. Additionally, he revealed that he did not understand the word predator as he used it wrongly in the context. The teacher did not exploit the moment that arose. Instead of involving the students in a discussion about what Tomas meant, she provided the answer and moved on. Furthermore, Dan attempted to explain why the different birds have different beaks by linking this to what they eat. This was a golden opportunity for the teacher to ask for elaboration and build on Dan's example to engage the rest of the class and further their understanding of the concept adaptation. Dan's effort, however, was not interpreted, or highlighted by the teacher as a step toward conceptual understanding. She just repeated briefly what she thought he meant without paying attention to his reasoning. These two examples concur with Myhill and Warren's (2005) type of critical moment that created confusion in learning because of the teachers' poor recognition of the impact of students' prior knowledge or understanding. A possible explanation for missing these opportunities to scaffold learning might be the teacher's level of pedagogical content knowledge (PCK). None of the participating teachers had any formal science background, and elementary school teachers' lack of science content knowledge and PCK is well documented in the literature (e.g., Bell, 2000; Harlen & Holroyd, 1997; Magnusson, Krajcik, & Borko, 1999). In this episode, in which the students attempted to describe and explain variation and adaptation, students' understanding is impeded rather than advanced by the teacher's short response ("That is why it has a beak like that") before she quickly moves on.

Episode 2

The next episode illustrates a slightly different missed planned teachable moment. It is from Emma's third-grade classroom, and the unit taught is Designing Mixtures, which includes the key concepts property, material, and design. In the previous lesson, the students read a book about materials and their properties, and they combined different materials and properties in a written task. Now the teacher has gathered the students to sum up what they have learned so far and prepare them for further investigations. The teacher's guide says that students should now be able to connect the properties of an object to the material it is made of. Additionally, the teacher is encouraged to help students understand the idea of people using properties to help them design new things.

> Teacher Emma (T): Do you remember what properties were? What could properties be?
> Maya: How it smells.
> T: Yes, let's take that first (writes smells on the flip-chart).
> Mona: Tastes.
> T: Tastes (writes).
> Dina: Sounds.
> T: Mm, sounds, shall we write that down? (writes).
> Christian: Feels.
> T: Feels, yes (writes). You remember a lot, I'm impressed. Mm, let's see. Now, what was material? What did that mean? Do you remember, John?
> John: Like rubber?
> T: Yes, rubber could be a material. But what is a material? Ida.
> Ida: It is what things are made of.
> T: Yes, what things are made of. Do you remember any materials? Dina.
> Dina: Metal.
> T: Yes (writes metal). Thea.
> Thea: Iron.
> Listing of materials continues until the teacher says they have to stop, and the students go back to their seats.

In this episode, no student response created a teachable moment; the planned activity of summing up itself created a platform for reinforcing new knowledge. At this point, students were expected to connect the properties of an object to the material it is made of. However, the teacher never requested such connections, and missed the opportunity to assess the students' ability to make the necessary links and help them clarify any confusion. A teaching strategy that focuses on memorizing definitions of concepts rather than challenging students to active thinking was described by Minner et al. (2010) as less demanding for the teacher and students. However, the authors also said this strategy is not very effective in terms of students' development of conceptual knowledge, and learning science words one-by-one limits the possibilities for learners to foster deeper understanding of science concepts (Cervetti et al., 2006).

Another teacher, Ellinor, taught the same unit to her third graders. As shown in the next section, she used the opportunities to further students' understanding in a similar summing-up sequence by interlinking the science concepts using a familiar context.

Planned Teachable Moments, Capitalized Upon

Episode 3

Ellinor also taught the unit Designing Mixtures to her third graders. The selected episode is from a similar sequence as example 2, in which students are supposed to demonstrate their understanding of how the properties of an object are connected to the material it is made of. Ellinor started out like Emma in episode 2 by asking for a definition of the words property and material. In Ellinor's class, however, this was just an introduction to the discourse in which the main focus is how the concepts relate to each other and how to link them to a context that makes meaning for the students. This sequence was categorized as a planned teachable moment because the purpose was to reinforce new knowledge and the teacher could expect some confusion.

> Teacher Ellinor (T): Properties. What are properties? Sam, do you know?
> Sam: Something you can see, smell, taste, feel, or hear about a material.
> T: Yes. Touch your desk; can you say something about the properties of your desk? Elise.
> Elise: It feels smooth.
> T: Yes, it feels smooth. Now, the word material. In science, material and substances are what things are made of. Bouncy balls, for example. What are bouncy balls made of?
> Siri: Rubber.
> T: Yes, rubber is a material. If you want to design something, why is it important to think about the material?
> (no responses)
> Ok, let's say you were to design a chair (pulls out a chair), what should you think about?
> Lea: Ehh, how to make it.
> T: What kind of material would you use?
> Lea: Wood.
> T: Yes, you could use wood. Why is it smart to use wood? Sara: It's
> the legs, they should be of wood, because it's hard.
> Martin: Metal or plastic.
> T: Metal, plastic. Mm. Why?
> Martin: Because this chair here (stands up and point at his chair), has metal legs because they cannot break, and what I sit on is plastic. So it's a plastic chair.
>
> The discussion goes on for several minutes with the students suggesting different materials and explaining why they can, or cannot, be used to make different parts of a chair.

After the initial utterances of the summing-up sequence, it seemed like the students had a clear perception of properties and materials. Then, when Ellinor asked them to apply their new knowledge and think about why it is important to consider the material when designing new things, nobody responded. This was a typical incident in which students needed clarification and further explanations to develop a higher level of conceptual knowledge. The example shows that knowing the definitions and being able to use science concepts properly in short answers represents only the first step toward conceptual understanding (e.g., Bravo et al.,2008; Scott et al., 2011; Vygotsky, 1987). Ellinor responded to the students' confusion by pulling out a chair and use it as a concrete example to scaffold the students' understanding. She seized the opportunity, helped students in their learning process, and moved them onto a higher level of thinking. Thus, in this episode, the opportunity to enhance student understanding was created not by a student response but by the lack of one. According to Myhill and Warren (2005), this is an example of a critical moment in which the teacher is responsive to student learning and acts on their responses (or in this case, the lack of such) in a flexible manner.

Most of the teachable moments identified were categorized as planned. Some were capitalized upon by the teacher, either in the form of building on student responses or as exemplified in episode 3 with Ellinor, using the learning activity to create more opportunities for students to develop understanding. Even so missed planned teachable moments occurred most frequently. Different types of missed opportunities were recognized, ranging from ignorance of student responses and poor recognition of student understanding, as demonstrated in episode 1, to the recurrent situation in which the teacher accepted one-word answers and definitional knowledge, as exemplified in episode 2.

In the next section, two examples of spontaneous teachable moments are presented, one in which the opportunity to enhance student learning is omitted and one that capitalizes upon the moment.

Spontaneous Teachable Moments, Missed

Episode 4

In this first example of a spontaneous teachable moment, Anna's fifth-grade class is at the end of the second session of the unit Gravity and Magnetism. Key concepts the students have investigated this far include force, push, and pull. The students have read and discussed how forces act as a push or a pull between two objects, collected data through a hands-on activity, and presented their findings. Now the teacher is ending the discussion that followed the student presentations, and the excerpt shows the last dialogue before the teacher moves on to the next topic. The event was categorized as a spontaneous teachable moment because the teacher's plan was evidently to repeat the "correct" and agreed-upon answer a last time. It seems like she did not expect, and is not receptive to, any responses other than the definitional one. Consequently, she missed the opportunity to develop student understanding when a student (Erik) revealed his confusion regarding how forces work as a push or a pull.

> Teacher Anna (T): When we talked about what we saw, if it was a push or a pull, what did we find out? What did we agree upon? Erik.
>
> Erik: It was easier to find out how to pull them together. We didn't find a push.
>
> T: That we pulled the blocks apart with our hands, and then there was a force pushing them together, is that what you mean?
>
> Erik: Yes. That was easier to find.
>
> T: Mm, and then we agreed upon whether it was a push or a pull. Then we agreed on that. Because we found evidence. Right. Mm.

Anna missed the opportunity to further students' conceptual development when a teachable moment occurred as Eric disclosed his group's difficulties identifying force as a push. Instead of addressing the students' confusion, she responded in a way that indicated a focus directed toward the progress of the lecture rather than the students' needs. In Myhill and Warren's (2005) terms, this is an example of a critical moment that creates confusion in learning because of what seems to be poor recognition of students' experience, and because the teacher redirects student responses to her own predetermined agenda. This type of teachable moment, labeled spontaneously occurring teachable moments, typically emerged when the teacher was ready to end an activity, and a student utterance created a moment of choice for the teacher. In this moment, as the teacher was ready to move on to the next teaching sequence, her response to the student utterance determined whether the moment was capitalized upon or not.

Similar to Myhill and Warren's (2005) findings, sticking to the planned task and objectives was the general pattern for the teachers in this study. As a result, only a small number of the spontaneous teachable moments identified were capitalized upon.

One of the teachers, Birgit, managed to take advantage of an unplanned situation. In the next section, an example from her classroom is presented, demonstrating how a spontaneous occurring teachable moment can be utilized.

Spontaneous Teachable Moments, Capitalized Upon

Episode 5

Birgit taught a unit on body systems to her fifth graders. Key concepts included system, structure, and function. First, the students learned about systems in general and finished a hands-on activity putting together a pumping system that sorted tiny balls of different sizes through a filter. The students also presented and discussed their findings. The class was ready to move on to the next session in the unit when the teacher's last comment caught the students' attention and created a moment of choice for the teacher.

> Teacher Birgit (B): It would have been nice to have such a ball sorting system in the sports hall to sort the tennis balls, footballs, handballs, and basketballs. I wonder what we would need to build a system like that. Well, that's a discussion for another time.
>
> (Several students raise their hands.)
>
> T: Wow, so many of you want to say something about this ball sorting system? (students nod). Ok, talk in your groups for a couple of minutes what you need to consider if you should build a system like that. (Students talk in groups for two to three minutes).
>
> Ada: We don't think it's possible with only one tube, because there can be only two sizes of balls in each tube. If you have three balls and the football goes through, then the handballs may go through as well, and they won't be sorted.
>
> T: Ahh. Did you all get what Ada said?
>
> Some students: Mm, yes.
>
> T: In your groups, use your own words and talk about what it was Ada meant.

In the following whole class discussion, the students built on Ada's response and suggested different solutions for how to design a functioning ball sorting system. Birgit directed their attention toward how the structure and function of the different parts make their system work or not.

Even though Birgit's reaction indicated that she did not plan for an elaborated discussion on how to design a bigger and more complex system, she saw the engagement this evoked in her students. She seized the opportunity to let her students apply their new knowledge to an everyday situation. Helping students make links between relevant scientific concepts and to see the connection between scientific construction and everyday experiences are types of link-making Scott et al. (2011) highlight as necessary to support knowledge building. In addition, building on Ada's response made the discourse revolve around a specific point of view instead of an anonymous perspective. This encourages positive emotional engagement, which is central in the development of conceptual understanding (e.g., Scott et al., 2011). Myhill and Warren (2005) referred to episodes like this as a critical moment in which the teacher responds to student learning by allowing students to explore the concept being taught in a different way.

Discussion and Implications

The purpose of this study was to identify the nature of the teachable moments observed, and subsequently whether and how they were used by the teacher to enhance student learning. Two types were identified, planned and spontaneous teachable moments. The first occurred more frequently than the latter, and was created predominantly by the learning activity itself and by student utterances or lack of such. Spontaneously occurring events were scarce, but those identified created alternative opportunities for the teacher to follow the pace of the curriculum or adapt to students' need. If, as some researchers suggest (e.g., Hyun & Marshall, 2003), a teachable moment presents itself when a student expresses a spontaneous interest or readiness, it can be far between teachable moments, and even farther between those capitalized upon. Instead, if teachers plan for teachable moments, they have the possibility to be better prepared to respond to the opportunities that arise and move students to another level of learning. Planned teachable moments in inquiry-based science are, to a certain degree, predictable, while spontaneously occurring ones are not. Therefore, it is fruitful to concentrate on teachable moments that can be planned for when making suggestions for how teachers can capitalize upon the opportunities provided and turn them into learnable moments. Knowing the importance of discussing and drawing conclusions from collected data in order to develop conceptual knowledge (e.g., Asay & Orgill, 2010; Minner et al., 2010), as a first step, teachers need to plan for events during which students can discuss shared experiences from their first- or secondhand investigations. Second, teachers need to know how to capitalize on the planned sequences. These two requirements are further discussed in the following subsections.

Planning for Teachable Moments

Teachable moments occur during different phases of inquiry, and can be planned for. Since reinforcement of new knowledge and development of conceptual understanding typically take place when students discuss their empirical findings and link them to established science, teachers must plan carefully to include enough time for discussion and communication during inquiry-based science instruction. Furthermore, when students share common experiences with the phenomena investigated, the students most likely have different perceptions and opinions. Teachers should therefore expect, and prepare for, that utterances from students or the teachers themselves can create moments especially suited for learning during these phases of inquiry. However, this requires that teachers recognize that inquiry- based science means more than doing hands-on activities. Teachers need to turn away from focusing primarily on the process, and instead spend more time on sense- making and consolidation of new knowledge as suggested in several studies (e.g., Kang et al., 2008; Ruiz-Primo & Furtak, 2007). A vast amount of literature discusses how teachers' beliefs about science and science teaching influence and shape their interpretations of curricular and instructional approaches (e.g., Anderson, 2002; Borko & Putnam, 1996; Crawford, 2007; Lotter, Harwood, & Bonner, 2007), and Schneider and Krajcik (2002) stated that changes in curriculum and standards do not automatically mean changes in teachers' practice. Schneider and Krajcik (2002) suggested educative curriculum materials designed to support teacher learning as well as student learning as one way to help teachers enact inquiry-based science teaching (Ball & Cohen, 1996). Teachers in the present study implemented curriculum materials providing teacher support in the form of a step- by-step guide that included in-depth science background, instructional strategies, and assessment. As a result, the teachers applied entire cycles of inquiry involving communication and discussion phases that create opportunities for teachable moments. Even so, results illustrate that this is not sufficient for all teachers to engage students in developing deeper conceptual knowledge. As Anderson (2007) argued, materials are of major importance, but materials alone cannot do the job. Findings indicate that scaffolding of student thinking and learning requires that teachers know when the opportunities are likely to occur, and how to capitalize upon them as they arise. This is not an easy task as it involves understanding of content and pedagogy as they come together, which supports Capps et al.'s (2012) statement that teachers need a considerable amount of content knowledge and pedagogical knowledge to teach inquiry-based science. Therefore, both teacher training and professional development courses focusing on inquiry-based instruction should include planning of teachable moments and provide training in strategies for capitalizing on them.

Capitalize Upon Planned Teachable Moments

Teaching materials can help teachers to plan for and facilitate teachable moments, but whether these moments are used to foster conceptual knowledge rests on the teachers' actions. This is a challenging task for teachers, and a recurring explanation is that elementary school teachers have a limited understanding of the science subject matter they are required to teach, and weak PCK in science (e.g., Appleton, 2008; Harlen & Holroyd, 1997). Likewise, Myhill and Warren (2005) listed low content knowledge as a reason why teachers miss the opportunity to build on a student's response. In the present study, in which teachers followed a detailed teacher's guide during a full inquiry cycle, teachers' lack of PCK might be one explanation for missed opportunities to scaffold students' conceptual development. Even though teachers' level of PCK cannot be directly inferred from the data set, the observed absence of strategies recommended to support student understanding such as extended discussions of empirical material that included justifying data (Asay & Orgill, 2010), inter-connecting concepts, and applying new knowledge in a context (Bravo et al., 2008; Scott et al., 2011) support this as a possible explanation. Teachers' traditional approach to science learning, e.g., teaching definitional knowledge, can also be connected to their beliefs about how science should be taught (e.g., Crawford, 2007). The interpretations of the data material in this study could have been elucidated through teachers' comments. However, regardless of teachers' level of content knowledge or their decision making processes, what was observed in the videotapes was valuable as it provided examples of how teaching and learning in an inquiry-based classroom looks like, including whether learning was facilitated and supported. As these findings suggest, for elementary school teachers to successfully enhance student conceptual knowledge through inquiry, more support is required in terms of how to plan for and effectively utilize the consolidation phases of inquiry. Professional development courses need to address teachers' content knowledge and PCK, as well as challenge their epistemological beliefs about inquiry-based science teaching and learning. This is in line with Capps et al.'s (2012) recommendation that several features need to be considered simultaneously to design effective inquiry professional development for in-service teachers.

Concluding Words

This study is not intended as a criticism of the teachers' practice, but as a way to highlight aspects of inquiry-based science and conceptual learning that were not apparent to the participating teachers and therefore necessitate attention. One limitation of this research is that this was the teachers' first time implementation of an inquiry-based curriculum, and research has linked greater student gains to teachers' increased experience with the curriculum (Fogleman, McNeill, & Krajcik, 2011).

Another limitation relates to the small sample. The results, nevertheless, highlight insights that can add to the knowledge base concerning the conduct of inquiry-based science lessons and conceptual learning. Additional data sources like teacher interviews might shed further light on the investigated phenomenon and provide more in-depth understanding about teachers' moves. This involves mapping of teachers' ideas and thoughts regarding teachable moments in science inquiry as well as their confidence in teaching science and views on own level of content knowledge. For further research it would also be valuable to examine the whole inquiry cycle to identify teachable moments occurring at different stages, and how this could be planned for and utilized.

Results from the present study point to topics and content important for teacher training and professional development, including how student investigations can be used as a tool for scaffolding students' understanding of science concepts. This, however, requires a focus on how teachers can engage students in discussions that build on evidence collected through investigation, including what teachers should look for in student responses and how to act upon these to promote conceptual understanding. As a follow-up, and to help teachers enact science inquiry effectively, more research is needed that provides examples from classrooms, not only on what makes it effective but also how to conduct science inquiry in ways that enhance student learning.

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APPENDICES

A. Coding scheme for the Budding Science and Literacy video study

B. Questionnaire

C. Interview guides

D. Letters of information

Appendix A

Coding scheme for the Budding Science and Literacy video study

BUDDING SCIENCE AND LITERACY

A CLASSROOM STUDY ON INQUIRY-BASED SCIENCE AND LITERACY

Categories for video
analysis of science lessons

by Marianne Ødegaard, Sonja M. Mork,
Berit Haug & Gard Ove Sørvik.

Oslo, 2012.

NATURFAGSENTERET
NORWEGIAN CENTRE FOR SCIENCE EDUCATION

BUDDING SCIENCE AND LITERACY
Do it! Talk it! Read it! Write it!

1 Coding Scheme: Activity Type

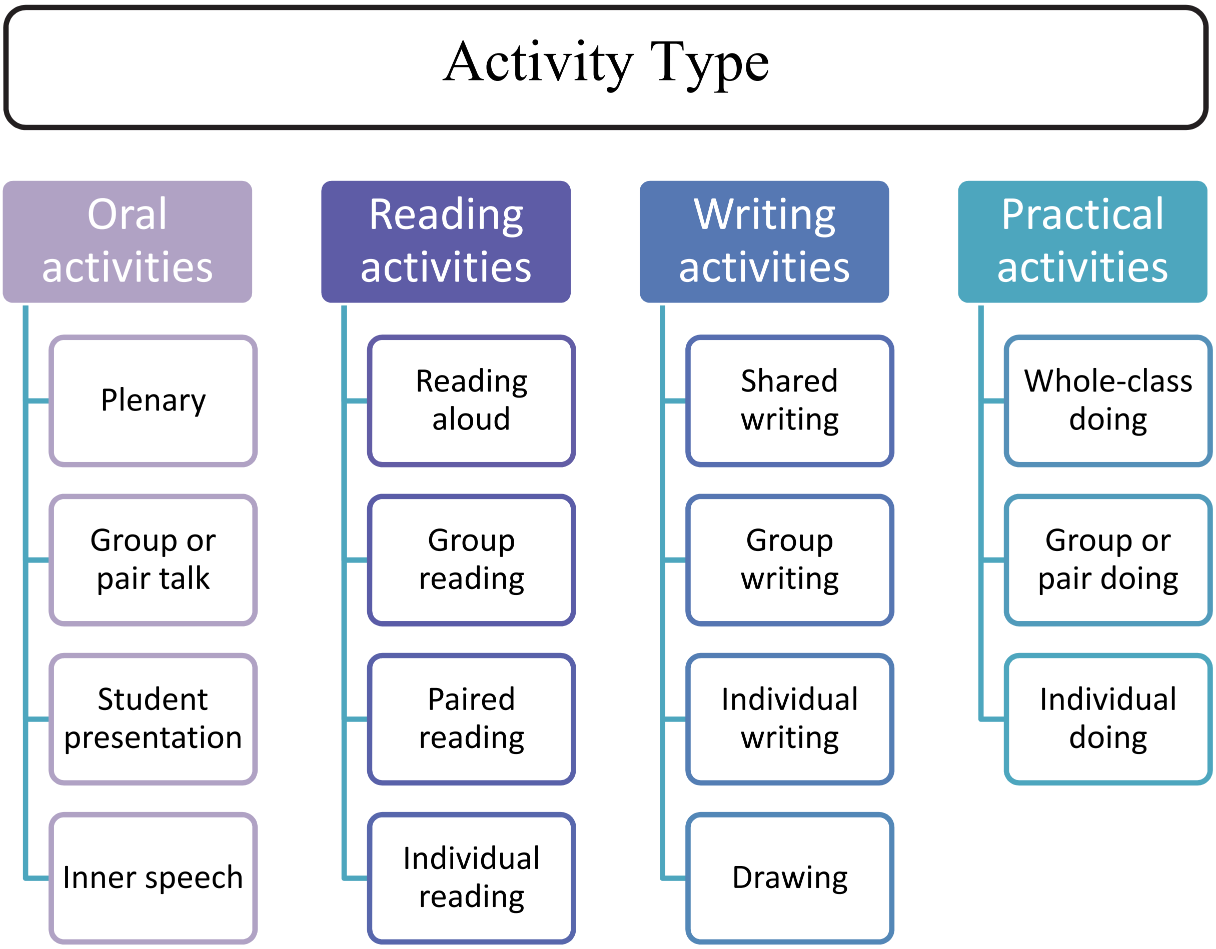

Figure 1. Overview of Activity Type Coding Scheme - Budding Science and Literacy

BUDDING SCIENCE AND LITERACY
Do it! Talk it! Read it! Write it!

Table 1. Activity Type Coding Scheme - Budding Science and Literacy

Oral activities	Description of code
Plenary	Teacher-led whole-class talk
Group or pair talk	Students are asked to talk in groups or in pairs about something subject-specific.
Student presentation	Students present their own work.
Inner speech	Teacher asks students to reflect on something or think about something.
Reading activities	
Reading aloud	Reading aloud in classroom by teacher or student, or choral reading.
Group reading	Students read in groups.
Paired reading	Students read in pairs, for example by reading every other line aloud to each other.
Individual reading	Students read silently.
Writing activities	
Shared writing	Teacher and students collaboratively compose a piece of writing. The code also covers modelled writing by the teacher.
Group writing	Students collaboratively compose a piece of writing.
Individual writing	Students individually compose a piece of text.
Drawing	Students make charts, figures, diagrams etc.
Practical activities	
Whole-class doing	Teacher and students do practical work as a part of the whole-class setting. This may involve a teacher demonstration or the teacher and students working together on a larger experiment.
Group or pair doing	Students do practical work in groups or in pairs.
Individual doing	Students do practical work individually.

2 Coding Scheme: Science Inquiry

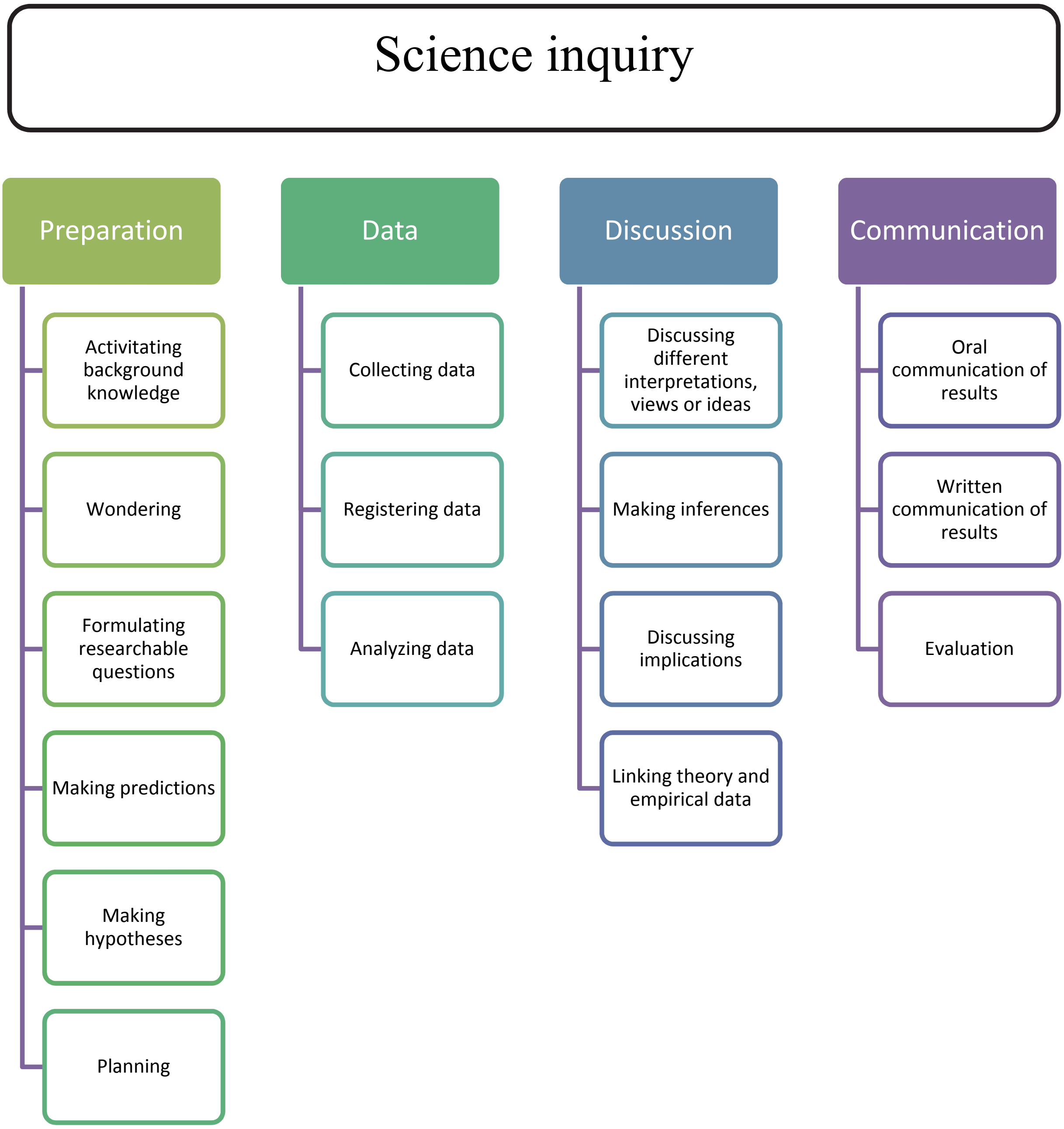

Figure 2. Overview of Science Inquiry Coding Scheme - Budding Science and Literacy

Table 2. Science Inquiry Coding Scheme - Budding Science and Literacy

Preparation	Description of code	Teacher utterances that might initiate the code
Activating background knowledge	Teacher-initiated activities, in which the teacher makes links to previous science lessons, everyday experiences or students’ prior knowledge, or enables the students to do so.	“Do you remember when we…?” “How many senses do we have?”
Wondering	The teacher initiates an activity to cause wonderment. For example by showing the students a cherry pitter and asking them “What do you think this is used for?”	“How can you separate the blue balls from the yellow balls?” “What do you think this is?”
Formulating researchable questions	The students (or in co-operation with teacher) formulate researchable questions.	“Is this something you want to find out about?” “What can we find about about animals by watching a video? Try to make your own questions.”
Making predictions	The students make a prediction.	Which of these types of glue will be the most effective?
Making hypotheses	The students explicitly make a hypothesis—a tentative explanation that can be tested with further investigation.	“Why do you think that?” «Write down why you think that this glue is the strongest.”
Planning	The students (or in co-operation with teacher) plan how they are going to investigate something.	“Make a plan for how you are going to sort the different ball sizes.”
Data		
Collecting data	The students (or in co-operation with teacher) collect data through firsthand or secondhand investigations. They make observations, do practical activities, or gather data from text.	“Use the picture of page 4 to make observations on how the sea turtle moves” “Begin testing out your system for sorting balls of different sizes”
Registering data	The students (or in co-operation with teacher) review or register data from their inquiry.	“What did you observe? “ “Write down your observations“
Analyzing data	The students (or in co-operation with teacher) work with and organize data by categorization.	“Which observations could you make for all the animals you observed?”

Discussion		
Discussing different interpretations, views or ideas	The students (or in co-operation with teacher) discuss different interpretations of the data they have collected or analyzed. The students discuss different views or exchange ideas.	“What is the structure of this wheel?”
Making inferences	The students (or in co-operation with teacher) make inferences based on data/evidence.	“What can this tell you about its function?” “What can you say about these two animals based on the observations we’ve made?”
Discussing implications	The students discuss implications of their findings, or of their different interpretations. They come up with new questions as a result of their inquiry.	“Would a bicycle wheel without its spokes work?” “But what if…?”
Linking theory and practice	The students link findings from their inquiry to theoretical perspectives. This may include scientific laws and theories, published research results, or information from their textbook or other informational science texts.	“What is the function of the tube in the system you have made?”
Communication		
Oral communication of results	The students communicate their findings orally to other students in the class or another recipient. Results are here taken to include both process and product of the students’ inquiry.	“Present the system you’ve made and how you thought of making it”
Written communication of results	The students communicate their findings through text. There is a clear aim for writing and a viable reader in mind.	“You are now going to communicate your findings to someone who has not been working with this topic the way you have” “Make a brochure that shows…”
Evaluation	The students evaluate their investigation and results. Could anything be done in a different way? Did they face any obstacles along the way? What effort did they put into the work? In which ways did they work like scientists? Evaluation may be both oral or in writing.	“Was there any challenges along the way?” “Why did you choose to do this instead of that?” “How does this compare to how scientists work?”

3 Additional codes for NOS and key concepts

Table 3. Code description for the code Nature of Science (NOS).

Nature of Science	Description of code	Teacher utterances that might initiate the code
	The code is used every time the teacher or the students makes reference to working like scientists or to “the” Nature of Science (NOS).	“How do scientists work? “

Table 2. Code description for the code Key Concepts.

Key Concepts	Description of code	Teacher utterances that might initiate the code
	The code is used every time the teacher or the students explicitly talk about the meaning of a concept or about how words and concepts are used.	“Observation means using all of your senses”

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[1] *Norwegian Centre for Science Education, Oslo, Norway.*

[2] *Department of Teacher Education and School Research, University of Oslo, Oslo, Norway.*

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Appendix B

[my translation]

Questionnaire, Science Education NATDID 1020

How long have you been teaching?

☐ 0–5 year(s)
☐ 6–10 years
☐ 11–15 years
☐ 16–20 years
☐ 21–25 years
☐ 26 years or more

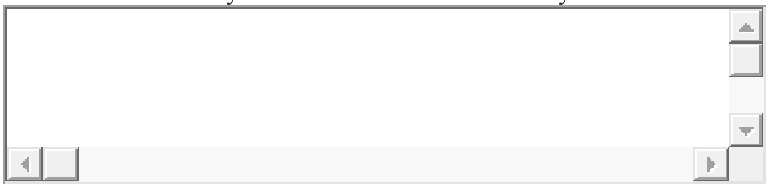
What education do you have in science subjects after high school?

☐ Nothing
☐ 15 study points or less
☐ 16–30 study points
☐ 31–60 study points
☐ 61 study points or more

What education do you have in language arts after high school?

☐ Nothing
☐ 15 study points or less
☐ 16–30 study points
☐ 31–60 study points
☐ 61 study points or more

- Please describe how you work with science texts in your class.



- Please describe how you teach scientific concepts.

- Please describe how you work to improve your students’ reading competencies.

- Why do you find it important to integrate science and literacy?

- What benefits do you think students can get by integrating science and literacy?

- Please describe how you facilitate inquiry activities for students.

- Please briefly describe a science lesson you considered successful.

- What are your expectations for this course?

Appendix C

[my translation]

Interview guides for teachers in the Budding Science and Literacy project

Interview 1, before implementation

Introduction

1. What are the attitudes toward science education at your school? (management, colleagues, science subject groups?).
2. What subjects do you teach?
3. What is your educational background?
4. When did you receive your teacher's diploma? How many years have you been teaching?
5. How long have you been teaching this group of students?
6. Are there any specific challenges connected to this group of students? (language, behavioral, etc.) If so, how do you meet these challenges?
7. How would you describe the social interactions in this group?

Conceptual understanding

8. When doing inquiry-based science, what do you think of the student outcome in terms of conceptual understanding of the scientific phenomenon investigated? (What do they learn: The practical part? Scientific processes? Content knowledge?).
9. Do you deliberately use scientific or everyday language? (Is the use of language more spontaneous with no specific strategy?)
10. How do you teach scientific concepts? (Which concepts are explained? Systematic use? Do you separate between the meaning and use of content-specific words and words connected to inquiry?)
11. In your opinion
    - What is the best way for students to learn scientific concepts?
    - How important is it to focus on concepts in science?
    - At what age can students be introduced to scientific concepts?

12. How do you assess students' prior knowledge?
13. How do you activate students' prior knowledge?
14. When, and how, do you consider that a student has understood a scientific concept?
15. When assessing a student's understanding of the content of a concept, what do you use as indicators of learning?
16. Do you have a specific strategy for when to move on with the lesson? For example, when assessing students' understanding of a concept, what determines when to move on?
17. What do you think of your students' perception of the feedback you provide? (What kind of feedback do you provide? Explicitly addressing the learning goals? Do you think the students know what part of the learning goal they have understood? How?).
18. Are there times during teaching when you have felt insecure regarding the subject matter knowledge? (If so, can you provide an example including how you handled that?)

Reading and writing

19. What is the role of writing when teaching and learning science concepts in your class?
20. Is writing emphasized equally as reading when working with science concepts? (Any thoughts on the role of reading and writing when teaching for conceptual understanding?)

Argumentation

21. In your science class, is there a focus on students justifying their answers? (How?)
22. If students justify their answers, do they need to base it on evidence? (In which situations? Any examples?)
23. Do you discuss and debate in science lessons? (How? Role play?)

Beliefs

24. What activities will you define as inquiry-based activities? (What characterizes inquiry-based activities?)
25. In your opinion, what role do creativity and imagination have in science?

Thank you!

Interview 2, after implementation

Introduction

This interview is being conducted as part of the development of the Budding science teaching model. You have adapted and implemented teaching materials from the American Seeds of Science/Roots of Reading to the local context of your classroom, and we need your opinions and advice to develop and refine the teaching model. This includes how the different activities can be adapted to a Norwegian context and to learn how these activities contribute to student learning.

1. Have there been any changes in your class since the last interview? If any, has it affected the social environment in class?
2. Did you find it distracting that researchers were present in the classroom?

Teaching of the chosen unit

3. How does the Budding science and literacy unit you chose correspond with
   - the national curriculum?
   - the textbook?
4. In the lessons when we (the researchers) were present in the classroom, is there anything you want to comment upon?
5. What is your overall assessment of the unit? (Anything that was especially successful?)
6. Was there anything you would have done differently? (Anything that was problematic or challenging?).
7. If you think about the lessons when we were present in the classroom, would you describe this as typical science lessons? If not, what was different from your typical teaching methods?
8. Do you consider the science lessons in this unit as successful for you as a teacher? (In terms of goal achievement, enactment, student participation, teacher–student interaction, student-student interaction, engagement for teacher and students. Why? Why not?).

9. How do you consider students' understanding of the scientific phenomena being investigated? (Was there any indication of increased understanding of subject matter knowledge when doing and discussing the hands-on activities?)

Conceptual understanding

10. What is your opinion regarding teaching and learning of science concepts in this curriculum? In what ways, if any, was it different from how you normally teach?
11. Did the detailed teacher guide provide enough room for teachers to make individual adjustments when teaching science concepts?
12. What is your opinion on the pre-selection of key science concepts? (Were there any words or concepts missing? Was there too many concepts? Was there too much focus on the pre-selected set of concepts?)
13. Students meet the selection of key concepts multiple times throughout the unit. In your opinion, did this have any effect on student learning? (If so, how did you notice?)
14. Can you say something about student understanding of the science concepts? Did the teaching material contribute to promoting student learning of subject matter knowledge? (If so, how? Examples from the lessons.)
15. How do you assess students' understanding of a concept? Did the material provide any support to assess student understanding? (Examples from the lessons)

Dialogue

16. In the professional development course, dialogues have been discussed, especially when and how to open up for student involvement. Did the teaching material support any student–teacher dialogue? Was there room for student initiative and questions? (If so, how did this work out? Examples from the lessons.)

Previous knowledge

17. In the unit you taught, was there any focus on students' previous knowledge?
18. How was students' previous knowledge activated and assessed?
19. Was the information students revealed used in the following activities?
20. How did this compare to the way you normally teach?

Assessment

21. As a teacher, you continuously assess students in a range of matters, for example, their conceptual understanding or if they have reached a learning goal. When, and how, do you consider that a student has understood a scientific concept? What makes you decide when the student is ready to move on? Do you have any specific strategy?

22. What do you think of your students' perception of the feedback you provide? (What kind of feedback do you provide? Explicitly addressing the learning goals, for example, the content of a science concept? Do you think the students know what part of the learning goal they have understood? How?).

Final words

23. Is there anything else you want to comment upon regarding the enactment of this curriculum?
24. Do you think you will continue to teach according to some of the principles in this curriculum? If so, what and why?
25. Are there any principles you will not use in your teaching?

Thank you!

Appendix D

[my translation]

Letters of information to students, teachers, and school principals

Naturfagsenteret
Nasjonalt senter for naturfag i opplæringen

Marianne Ødegaard
Postboks 1106 Blindern
0317 Oslo
Telephone: +47 22 85 81 15
E-mail: marianne.odegaard@naturfagsenteret.no
Internet: www.naturfagsenteret.no

To students at XXXX school Oslo, XXXX 2010

Invitation to participate in the research project «Budding science and literacy»
Budding Science and Literacy is a project that aims to develop teaching materials in science in which practical activities are combined with reading, writing, and oral competencies. The research project is being conducted by the Norwegian Centre for Science Education, University of Oslo, and is funded by the Norwegian Research Council. We have invited teachers at your school to contribute and help us increase our knowledge of successful teaching and learning in science subjects.

In the project, researchers and teachers will collaborate to develop and improve science teaching and learning. This involves following teachers and students when they plan, do, and discuss science activities. We will video- and audiotape the lessons, and researchers will be present during instruction. There will also be video-recorded interviews with teachers and students after the lessons. This study follows various teachers and students over time, and the data material might be used in later studies. Only researchers who are connected to the project and familiar with this agreement have access to the material. The researchers' presence in the classroom will take place in agreement with the teacher. We will visit the school several times throughout the school year.

Registration, storing, and reporting of data follow the guidelines of the law of personal information storage. The collected information will be treated confidentially, and only by persons employed in this project. The results from this investigation will be presented in a way that makes it impossible to trace the information back to the persons who participate in the research. Some video recordings may be presented at research conferences and for educational purposes, in those cases; participants will be asked for additional consent. Recordings will never be available on the Internet. The project is registered in the Data Protection Office for Research, Norwegian Social Science Data Services (NSD).

Participation is voluntary, and it is possible to withdraw at any time without having to provide an explanation. If someone withdraws, information regarding this person will be anonymized as soon as possible. The recordings will be deleted, and all information will be made anonymous by the end of the project in December 2030.

We ask for your consent to collect audio- and video recordings and to perform interviews. Agreement of participation requires that the student and a parent/caretaker sign this letter.

Best regards,

Anders Isnes	Marianne Ødegaard	Sonja Mork
Leader	Project leader	Associate professor

☐ I give my approval to take part in the research project. I am aware that this involves being audio- and videotaped.

Student name and signature Parent/caretaker signature

Naturfagsenteret
Nasjonalt senter for naturfag i opplæringen

Marianne Ødegaard
Postboks 1106 Blindern
0317 Oslo
Telephone: +47 22 85 81 15
E-mail: marianne.odegaard@naturfagsenteret.no
Internet: www.naturfagsenteret.no

To teacher at XXXX school Oslo, XXXX 2010

The research project «Budding science and literacy»
Budding Science and Literacy is a project that aims to develop a teaching program that integrates inquiry-based science and literacy and facilitates teaching and learning for Norwegian teachers and students. The research project is being conducted by the Norwegian Centre for Science Education, University of Oslo, and is funded by the Norwegian Research Council. We are pleased that you have volunteered to contribute to the project.

In the project, researchers and teachers will collaborate to develop and improve science teaching and learning. This involves following you and students when you plan, do, and discuss science activities. We will video- and audiotape the lessons, and researchers will be present during instruction. Furthermore, there might be video-recorded interviews with you and some of the students after the lessons. This study follows various teachers and students over time, and the data material might be used in later studies. Only researchers who are connected to the project and familiar with this agreement have access to the material. The researchers' presence in the classroom will take place as agreed with you. We will visit the school several times throughout the school year. The scheduled time for collecting data for this project is fall 2010 to spring 2012.

Registration, storing, and reporting of data will follow the guidelines of the law of personal information storage. The collected information will be treated confidentially, and only by persons employed on this project. The results from this investigation will be presented in a way that makes it impossible to trace the information back to the participating students, teachers, class, or school. Some video recordings may be presented at research conferences and for educational purposes,; in those cases, participants will be asked for additional consent. Recordings will never be available on the Internet. The project is registered in the Data Protection Office for Research, Norwegian Social Science Data Services (NSD).

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We ask for your consent to collect audio- and video recordings and to perform interviews. Agreement of participation requires that you sign this letter.

Best regards,

Anders Isnes	Marianne Ødegaard	Sonja Mork
Leader	Project leader	Associate professor

☐ I give my approval to take part in the research project. I am aware that this involves being audio- and videotaped.

Date, place Teacher's name and signature

Naturfagsenteret
Nasjonalt senter for naturfag i opplæringen

Marianne Ødegaard
Postboks 1106 Blindern
0317 Oslo
Telephone: +47 22 85 81 15
E-mail: marianne.odegaard@naturfagsenteret.no
Internet: www.naturfagsenteret.no

To the principal at XXXX school Oslo, XXXX 2010

The research project «Budding science and literacy»
Budding Science and Literacy is a project that aims to develop a teaching program that integrates inquiry-based science and literacy and facilitates teaching and learning for Norwegian teachers and students. The research project is being conducted by the Norwegian Centre for Science Education, University of Oslo, and is funded by the Norwegian Research Council. We have been introduced to specific teachers at your school through the professional development course Integrating Science and Literacy provided by the Norwegian Centre for Science Education/University of Oslo. We are pleased that the teachers have volunteered to contribute to this project.

The research project is part of a longitudinal study over seven years and involves measures for teachers and students in science education. The project is funded by the Norwegian Research Council's Programme for Norwegian Educational Research towards 2020.

The project can be described as an intervention study in which researchers and teachers collaborate to develop and improve science teaching and learning. We consider the professional development course the intervention. This involves following the teacher and students when they plan, do, and discuss inquiry-based science activities. As part of this work, we will video- and audiotape the lessons, and researchers will be present during instruction. Furthermore, there might be video-recorded interviews with the teacher and some of the students after the lessons.

Our presence in the classroom will take place in agreement with the teacher. It is preferable to visit the school several times throughout the school year. Scheduled time for collecting data for this project is fall 2010 through spring 2012.

Registration, storing, and reporting of data will follow the guidelines of the law of personal information storage. The collected information will be treated confidentially, and only by persons working on this project. The results from this investigation will be presented in a way that makes it impossible to trace the information back to the participating students, teachers, class, or school. Some video recordings may be presented at research conferences and for educational purposes; in those cases, participants will be asked for additional consent. The recordings will never be available on the Internet. The project is registered in the Data Protection Office for Research, Norwegian Social Science Data Services (NSD).

We want to emphasize that the quality of the study depends on the teacher and students allowing researchers access to the classroom activities. Our intention is that the teachers, students, and schools will find this collaboration interesting, informative, and useful for further development.

Best regards,

Anders Isnes	Marianne Ødegaard	Sonja Mork
Leader	Project leader	Associate professor