Open inquiry in science classrooms: exploring and developing teachers' practices in upper secondary school

Åpne utforskende arbeidsmåter i naturfag: forskning og utvikling av læreres praksis i videregående skole

Philosophiae Doctor (PhD) Thesis

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Ås 2014

Thesis number 2014:77
ISSN 1894-6402
ISBN 978-82-575-1237-8

Forord

Doktorgradsarbeidet er snart ved veis ende. Det har vært en lang tur med utforskning i ukjent terreng – preget av både glede og frustrasjon. Det å finne sin egen sti har vært viktig, men kunne ikke vært gjort uten alle lærerike og givende møter med mennesker underveis – det er mange som fortjener en stor takk for veiledning, gode samtaler og oppmuntring.

Først og fremst vil jeg takke min hovedveileder Erik Knain for å ha vært en dyktig og tålmodig veileder, og for å ha invitert meg inn i prosjektet ElevForsk. Du har gitt meg spillerom og tillitt, samtidig som du alltid har vært tilgjengelig for veiledning, gode fagsamtaler og gjennomlesninger av alle tekster. Din faglige innsikt har jeg kunne nyte godt av i min utvikling som forsker. Det har også vært en stor glede å samarbeide med deg i aksjonsforskningsprosjektet, din åpenhet sammen med ditt analytiske blikk for det som skjer i klasserommet har vært svært inspirerende.

Jeg vil også takke min biveileder Stein Dankert Kolstø for å ha vært en inspirerende og støttende veileder og samarbeidspartner i ElevForsk. Dine gode kritiske spørsmål og konstruktive innspill i veiledningen har vært svært viktig for utviklingen av min forståelse av utforskende arbeidsmåter i naturfagene.

En stor takk til ElevForsk som ga meg en gyllen mulighet til å ta en forskerutdanning samtidig som jeg kunne fortsette i jobben som naturfagdidaktiker ved Seksjon for Læring og Lærerutdanning (SLL) ved NMBU. Jeg har vært støttet finansielt av Norges Forskningsråd gjennom ElevForsk-prosjektet til 40 prosent frikjøp fra undervisning i prosjektperioden. I tillegg har jeg fått anledning til å ta ett års forskningsfri takket være SLL og Institutt for matematiske realfag og teknologi. En spesiell takk til forskere og medstudenter i ElevForsk for det gode utforskende fellesskapet som har gitt rom for ideer, kritisk refleksjon og anledning til å sette ord på tankene. Mine medstudenter i prosjektet; Gerd Johansen, Idar Mestad, Anne Kristine Byhring – takk for alle inspirerende samtaler. En spesiell takk til Gerd, gjennom spennende diskusjoner og mye humor har samarbeidet med deg vært en stor glede og verdifull støtte gjennom hele PhD-løpet. Jeg vil også takke Sigrid Gjøtterud for å ha introdusert meg til aksjonsforskning og kommet med verdifulle innspill underveis, Marianne Ødegaard for engasjerende samtaler knyttet til utforskende arbeidsmåter, og Ola Erstad og Edvin Østergaard for gjennomlesing og gode innspill i sluttfasen.

Til alle ved SLL – dere er de beste kollegaer noen kan ønske seg. Jeg er takknemlig for all støtte gjennom disse årene; fra faglige innspill til omtanke når det har vært tungt. Og ikke minst for at dere så raust har avlastet meg i undervisningen for at jeg skulle kunne bli ferdig. En spesiell takk til seksjonsleder Hans Erik Lefdal for at du la til rette for at jeg kunne gjennomføre en PhD-

utdanning i kombinasjon med jobben. Og ikke minst en stor takk til Astrid Sinnes for å ha introdusert meg til naturfagdidaktikk som forskningsfelt og lokket meg til NMBU, og for all oppmuntring, faglige innspill og tro på arbeidet mitt – det har vært viktig for å holde ut. Takk til PhD-gruppa på SLL ved Anne Kristine, Kirsti, Franci, Snorre, Mette, Hayley, Athman, Elisabeth og Ingrid for alle gode samtaler. Og en varm takk til alle de fantastiske deltakerne i Project Sustain.

En stor takk til mine turkamerater Majken, Hanne og Kirsti; det har vært har vært en glede å dele PhD-turen med dere både i faglig og sosial forstand. Til mine gode venner og familie, takk for at dere har vært så interesserte, omsorgsfulle og tålmodige - og ikke minst at dere kontinuerlig har minnet meg på at det finnes andre gleder i livet.

Jeg vil rette en stor takk til lærerne, elevene og ledelsen ved Dale videregående skole som har deltatt i aksjonsforskningsprosjektet for å ha åpnet skolen og klasserommet for forskning og utviklingsarbeid. Det er modig gjort, og dette studiet kunne ikke ha blitt til uten dere. En spesiell takk til Amir som har vært pådriver og oppmuntrer fra skolens side, og som i tillegg har delt raust av sin kunnskap og tid.

Til slutt, den største takken fortjener John Roger som tålmodig har støttet og oppmuntret meg hele veien, og ikke minst våre fine barn, Pia og Clara, som har blitt over seks år eldre siden PhD-løpet startet. Dere er helt fantastiske – og nå lover jeg at det blir mer tid sammen til helt andre ting!

Oslo, august 2014

Birgitte Bjønness

Summary

The study was part of the research project StudentResearch (2007-2010), with the goal that students were to become knowledge builders in practices that have some common traits with scientific inquiry. The project was financially supported by The Research Council of Norway.

The thesis includes three articles representing three different levels concerning teachers' role developing science inquiry in a situated practice. The three levels are: (a) *the individual teacher* – how the teacher's beliefs bring scope and force to the practice of open inquiry in a situated practice; (b) *the science classroom* – how the teacher scaffolds the students during open inquiry; (c) *the school* – how science inquiry can be developed as a collaboration between teachers and researchers at school.

The first article offer an understanding why a positivist epistemology and related myths concerning NOS are robust in school versions of scientific inquiry even though they go against the "appropriate" views of the nature of science (NOS). The case study reveals that what seemed to be a teacher's positivist position towards NOS and scientific inquiry was embedded in a broader concern about pedagogical considerations and personal engagement with low-achieving students. The implications are that teachers (students) should be given the opportunity for guided reflections on personal experiences and commitment to scientific inquiry in order to become more conscious of how they affect their beliefs and practice.

The second article identify emerging issues concerning how the teacher support the students providing them with a balance of *structure and space* – and how it constitutes the students inquiry process in the different phases of the inquiry. The study indicate that there exist a necessary tension and interplay between structure and space, creating what can be seen as a driving force providing both exploration and direction for the open inquiry. The notion of "structure and space" is suggested as a thinking tool for teachers' (students) to increase competence on how to scaffold more authentic versions of scientific inquiry in school.

The third article explores possibilities and constrains with collaborative action research between teachers and researchers to improve science inquiry in school. It draws on two action research project within StudentReserach experiencing many similar challenges. In both practices we found that the *transition* between planning change and what happened in the actual classroom practice was difficult. We were also concerned about our role as researchers in the collaboration – how to bring in relevant perspectives from educational research. We suggests that the collaborative effort developing concrete *tools* for classroom practice of science inquiry can act as an impetus for change when it is supported by both educational literature and the situated practice. Thus, the *distinguished voices* of the teacher and researcher will complement each other and might act to bridge the gap between research and practice of science inquiry.

Sammendrag

Målet med denne studien er å utforske muligheter og utfordringer naturfaglærere erfarer når de skal utvikle utforskende arbeidsmåter i en situert skolepraksis. Jeg samarbeidet med naturfaglærere og en med-forsker i et aksjonsforskningsprosjekt om å utvikle og lære av en praksis med åpen utforskende arbeidsmåter ved en videregående skole. Studien er en del av ElevForsk prosjektet (2007-2010), med et felles mål om å analysere og utvikle hvordan elever kan bli forskende i sin egen læring i naturfag. Prosjektet ble finansiert av Norges Forskningsråd.

Avhandlingen inkluderer tre artikler som representerer tre ulike nivåer knyttet til læreres rolle ved utvikling av utforskende arbeidsmåter i praksis. De tre nivåene er: (a) den individuelle lærer - hvordan lærerens "beliefs" gir mening og drivkraft til åpne utforskende arbeidsmåter i en situert praksis; (b) naturfagklasserommet - hvordan læreren kan støtte og veilede elevene ved åpne utforskende arbeidsmåter; (c) skolen - hvordan utforskende arbeidsmåter kan utvikles gjennom samarbeid mellom lærere og forskere.

Den første artikkelen gir en forståelse for hvorfor en positivistisk epistemologi og tilhørende myter om av naturvitenskapelige tenke- og arbeidsmåter holder stand i skoleversjoner. Case studien viser at en lærers tilsynelatende positivistiske holdning var bakt inn i pedagogiske avgjørelser og personlig engasjement for gruppen elever med lav måloppnåelse i naturfag. Implikasjoner er at lærere (studenter) burde få anledning til veiledet refleksjon knyttet til personlige erfaringer og forhold til naturvitenskapelig tenke- og arbeidsmåte for å bli mer bevisst hvordan de påvirker deres "beliefs" og praksis.

Den andre artikkelen identifiserer hvordan læreren støtter og veileder elevene ved å gi dem en balanse av *struktur og spillerom* – og hvordan det konstituerer elevenes utforskende prosess i de ulike fasene av prosjektet. Studien indikerer at det eksisterer en nødvendig spenning og vekselvirkning mellom struktur og spillerom som skaper en drivkraft for både åpen utforskning og retning inn mot læringsmål. Begrepet "struktur og spillerom" blir foreslått som et verktøy for å øke læreres (studenters) kompetanse knyttet til hvordan støtte og veilede mer autentiske versjoner av naturvitenskapelige tenke- og arbeidsmåter i skolen.

Den tredje artikkelen diskuterer muligheter og utfordringer aksjonsforskning gir for å forbedre utforskende arbeidsmåter i naturfag. Artikkelen tar utgangspunkt i to forskningsprosjekter innenfor ElevForsk som erfarte mange liknende utfordringer. I begge praksisene fant vi at *overgangen* mellom å planlegge endring til gjennomføring i klasserommet var vanskelig. Vi forslår at samarbeid om å utvikle konkrete verktøy for undervisningen kan virke som en pådriver for endring når den støttes av både forskningslitteratur og den situerte praksisen. De ulike "stemmene" fra læreren og forskeren vil kunne komplementere hverandre og bygge bro mellom forskning og praksis knyttet til utforskende arbeidsmåter.

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PART I:

EXTENDED ABSTRACT

1 Introduction

> Teachers need to witness the joy and the excitement the students experience when they are allowed to do their own research. It's a lot of work, but it's worth it when you see your students grow with the task (Amir, 2010).

This quote comes from an experienced science teacher in the present study, explaining why he is performing open inquiry with his students. This study is part of a Norwegian research project called "StudentResearch" that focuses on how students can use inquiry approaches and work like scientists when they are learning science at school. The research project was initiated after the implementation of a Norwegian school reform in 2006, where the natural science subject revealed an increased focus on learning to engage in scientific inquiry and develop an understanding of the "nature of science" (NOS). The commitment to inquiry, both as structured investigations and in more open real-world settings, has long been a hallmark of science education (e.g., Crawford, 2014; Hofstein & Kind, 2012). However, despite several decades of research on school science inquiry and continuous effort in schools, teachers struggle to put inquiry into practice (e.g., Bencze, Bowen, & Alsop, 2006; Capps & Crawford, 2012; Windschitl, 2004). The point of departure for the present study is the key role teachers play in developing science inquiry in a situated school practice. We were two researchers collaborating with a group of science teachers at an upper secondary school, using action research to improve and learn from a practice of open inquiry (Carr & Kemmis, 2003; Hodson & Bencze, 1998).

The main aim of the thesis is to explore teachers' beliefs about NOS and scientific inquiry, the processes by which teachers carry out open inquiry, the consequences for the students' learning process, and teachers' motivation for undertaking a complex, and often difficult to manage, teaching approach. The thesis also explores how teachers and researchers can collaborate to develop a practice of science inquiry as a joint achievement in a situated practice. In the following, I will bring forth perspectives connected to three major dimensions of this study—*the teacher*, *science inquiry* and *school practice*—that prepare the ground for the rationale and the research questions driving the study.

Teachers are undoubtedly important persons in society. My own background as a science teacher and, later, a science teacher educator has convinced me that teachers clearly do make a difference. This is also what makes the students in our science teacher education program want to become teachers: They dream of making a difference in young people's lives. Teachers invest themselves and their sense of identity in their work. Norwegian Prime Minister Erna Solberg also recognises the important role teachers play in the realisation of a knowledge society. In January 2014, she put forward her vision to make the teaching profession a “dream profession”. From research, we know that the “teacher factor” in general is essential for students’ learning in the classroom (Hattie, 2009). There are science teachers who are succeeding with all kinds of teaching approaches, ranging from ‘direct’ instruction to inquiry-based teaching (Barnett & Hodson, 2001; Cobern et al., 2012). The question is what these good teachers know. Barnett and Hodson express the following view:

> The sources of this knowledge are both internal and external: internal sources include reflection on personal experiences of teaching, including feelings about the responses of students, parents, and other teachers to one’s actions; external sources include subject matter knowledge, gouvermental regulations, school policies, and the like. (Barnett & Hodson, 2001, p. 436)

The value of the reflective teacher is also put forward as a main idea by Hattie (2009) in his meta-study on learning: Good teachers are reflective, regularly evaluate the effect different teaching strategies have on their students, and are able to adjust their teaching methods accordingly. Taking into consideration the teacher’s key role in shaping the teaching practice and students’ learning environment, the desired change in school science depends heavily upon teachers’ capacity to integrate the epistemology of a reform with their beliefs and existing practices (Bryan, 2012; Keys & Bryan, 2001). Teachers attempting to move toward inquiry-oriented science education face several dilemmas in their classroom practice: inquiry takes more time; the ideal portrayal of inquiry in policy documents is in conflict with the reality in the classroom; roles for both teacher and students must change; and it is difficult to devote significant effort to inquiry, as teachers fear preparation for the next level of schooling will suffer (Anderson, 2007, p. 816).

Several studies have been conducted to test the efficacy of inquiry versus direct teaching. Some of these have been inconclusive (e.g., Cobern et al., 2012), while others showed a positive trend toward inquiry (e.g., Furtak, Seidel, Iverson, & Briggs, 2012). In her recent review of research concerning school science inquiry, Barbara Crawford (2014) found a movement away from asking if inquiry is “good”, and toward questions regarding how inquiry can be successfully enacted in science classrooms.

Teachers are under considerable pressure to adjust and develop their teaching as a result of education reforms. Roberts (2007) identifies the continuing political and intellectual tensions in science education: Should curricula emphasise science subject matter itself, or should they emphasise science in life situations in which science plays a key role? The latter scenario embodies a vision for ‘scientific literacy’, which is necessary for all young people, whatever their career aspirations or talents (Millar & Osborne, 1998; Sjøberg, 1998). Embodied in this vision is a concern regarding citizens' understanding of NOS. Reforms in science education all over the world advocate a view of teaching and learning that emphasises inquiry, on the assumption that this can increase interest in science (e.g., European Commission, 2007; National Research Council, 2000; Ministry of Education and Research, 2006). Moreover, there is widespread agreement amongst researchers, science teacher educators and school teachers that students should be given the possibility to experience science inquiry (Crawford, 2014; Lunetta, Hofstein, & Clough, 2007).

However, the meaning of the word "inquiry" in science education is far from clear (Anderson, 2002; Crawford, 2014), and teachers' views on what it means to do science inquiry are multifaceted (Asay & Orgill, 2010; Bryan, 2012). School science inquiry in the form of practical work is often framed almost as a recipe, which creates little room for reflections (e.g., Tiberghien, Veillard, Le Maréchal, Buty, & Millar, 2001). However, open inquiry, which is the focus of the present study, is suggested to replace the recipe-like version of practical work because it is more closely related to scientific activity and reasoning (Duschl & Grandy, 2008; Roth, 2012). Open inquiry can be described as a teaching approach in which students are supposed to learn about scientific inquiry and NOS, taking responsibility for developing ideas, planning, executing and reporting their own inquiries (Hodson, 2009; Roth, 2012; Zion & Slezak, 2005). Moreover, it is an opportunity for students to achieve some intellectual and creative independence.

Nevertheless, open inquiry happens relatively rarely and often portrays naïve versions of scientific inquiry that do not model professional science (Duschl & Grandy, 2008; Windschitl, 2004). There is a great deal of discussion over what learning outcomes actually result from open inquiry. Perhaps the most significant objection is that "doing science" is not sufficient for developing informed conceptions of NOS (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003; Schwartz, Lederman, & Crawford, 2004). Thus, inquiry in school provides possibilities for students learning about NOS and scientific inquiry; however, it is also characterised by many dilemmas and unanswered questions.

The Norwegian curriculum reform Knowledge Promotion (Ministry of Education and Research, 2006) led to an increased focus on the processes of science in the natural science subject. In Norway, limited research has been done on science inquiry in school. There exists some literature on practical work and scientific literacy (e.g., Kind, 2003; Knain, 2001; Kolstø, 2000; Sjøberg, 2012) and small-scale research has been done on science inquiry (e.g., Knain, 2008; Kolstø & Mestad, 2005; Ødegaard & Arnesen, 2010). However, more extensive empirical research on science inquiry in Norwegian schools only began to be conducted after the implementation of the reform Knowledge Promotion, through the present research project, StudentResearch, in secondary schools and the “Budding Science and Literacy” program (Ødegaard, Haug, Mork, & Sørvik, in press) in primary schools. Thus, there is a need for empirical research concerning science inquiry in Norwegian schools.

Moreover, the reform does not provide guidance for schools and teachers concerning what organisation and teaching methods are most suitable to realise the content of the curriculum for the students. This provides opportunities for teachers to reconstruct the curriculum at “grassroots level”. However, this is probably unlikely to happen taking into account the limited time teachers have to debate fundamental issues related to good curriculum design (Hodson & Bencze, 1998). In her review on science inquiry, Crawford (2014) found that there is a gap between practice and research of science inquiry that may contribute to the disparity between the intended curriculum of the reforms and the implemented curriculum. Moreover, the author suggests that it is important to investigate inquiry practices in teachers’ actual classrooms over longer periods of time, in addition to assessing teacher’s beliefs and knowledge.

An action research approach has been suggested as a possibility for curriculum development, taking account of the uniqueness of each educational situation and building on teachers’ professional knowledge, to ensure that all sides of the curriculum are under critical scrutiny (Herr & Anderson, 2005; Hodson & Bencze, 1998). Moreover, new visions for professional development are suggested within collaborative communities of teachers (European Commission, 2007; Goodnough, 2010).

1.1 Rationale and research questions

The rationale for the present study is the need for knowledge concerning the challenges and possibilities teachers experience in implementing open inquiry in a situated practice. The point of departure is educational research suggesting open inquiry as an approach to learn about NOS and scientific inquiry as a major part of science curricula. However, there also exists research revealing that open inquiry in the classroom often portrays naïve versions of scientific inquiry that do not model professional science, and thus does not fulfil the aims of understanding NOS and scientific inquiry. Research also reveals that teachers struggling to implement inquiry face several dilemmas in their classrooms. Thus, there exists a gap between formal curricula and what is happening in the classroom concerning open inquiry. Moreover, limited empirical research has been done on practices of science inquiry in Norwegian classrooms. Considering that the desired change depends heavily on teachers’ capacity to integrate the epistemologies and practices of a reform with their own beliefs and practices, a research approach taking account of teachers’ situated knowledge and researchers’ more theoretical perspectives is promising. This thesis is based on a case study using an action research approach at an upper secondary school for three years. Thus, it provided rich empirical data. I chose to focus in particular on one experienced science teacher and his day-to-day interactions with his students during an open inquiry project. This in-depth and longitudinal study can be of importance in providing context-dependent knowledge, increasing our understanding of scientific inquiry in school and the conditions necessary for change of practice. Moreover, implications for teacher education and professional development are suggested.

An overarching research question is formulated for the thesis:
How can teachers develop practice to support students' learning of science inquiry?

The thesis includes three articles in which there is a shift of framing representing three different levels about how a teacher develops open inquiry. The three levels are: (a) *the individual teacher* – how the teacher's beliefs bring scope and force to the practice of open inquiry in a situated practice; (b) *the science classroom* – how the teacher scaffolds the students during open inquiry; and (c) *the school* – how science inquiry can be developed as a collaboration between teachers and researchers at school. In the following section, I will present the research questions and aims guiding each of the three separate studies.

The main question driving the first single case study:

1. *How does a science teacher's belief concerning nature of science and scientific inquiry represent scope and force in a situated practice of open inquiry?*

The aim of the first article is to understand why simplistic versions of scientific inquiry are seen as purposeful in teaching even though they go against the "appropriate" views of NOS. In-depth interviews over the course of three years were used to identify the broader ecology of a teacher's beliefs concerning NOS and scientific inquiry, as well as how they guide the teacher's decisions and practice in a situated practice.

The main question driving the second single case study:

2. *How does a science teacher scaffold the students' learning of essential features of scientific inquiry and development of autonomy during open inquiry?*

The aim of the second article is to examine a teacher's scaffolding strategies supporting open inquiry. Interaction analysis was used to identify how the teacher provided the students with structure and space, and how it constituted the students' learning process.

The main question driving the third study was:

3. *How can the development of tools as a joint achievement between teachers and researchers mediate change in practice of inquiry?*

The aim of the third article is to discuss possibilities and constraints concerning collaborative action research as an approach to improve the practice of science inquiry. The article is built on reflections on two action research projects.

1.2 Clarifications

The case study methodology was used in this study for its ability to examine, in-depth, a case within its real-life context (Yin, 2009). The overall study exploring teachers' experiences developing open inquiry in a situated school context represents a comprehensive case, which includes several sub-cases. We were two researchers and three science teachers using collaborative action research to improve and learn from an open inquiry project at Dale Upper Secondary School from 2007-2010. The action research approach provided a large amount of data from the meetings supporting the action research process, and from actions in the classroom. Data was collected through: field notes, audio and video recordings, site documents and interviews with teachers and students. The comprehensive case at Dale Upper Secondary School is used in this thesis as a descriptive context, while the three articles are based on data solely from one of the science teachers, Amir, and his practice. The first and the second article are drawn from sub-cases, while the third article reflects upon experiences from the present action research project and a sister project within StudentResearch, both of which aim to improve science inquiry in upper secondary schools.

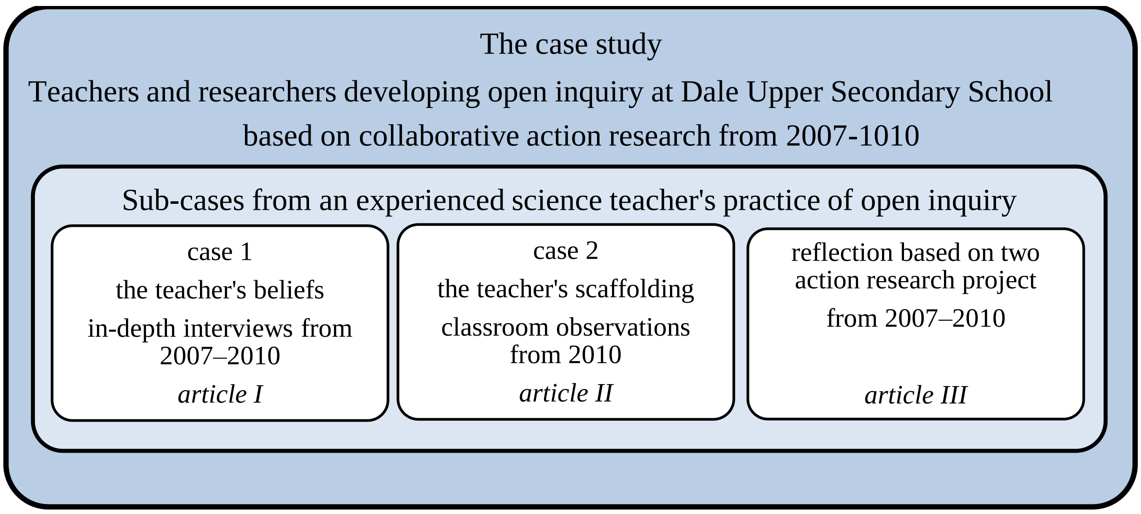


Figure 1. The relationships between the case study, the action research, the individual studies and the articles. Article III is not only part of this case study but also reports from another action research project.

1.3 My beliefs concerning teaching and learning science inquiry

In 1994, I got my first job as a science teacher at an upper secondary school. The previous year I had finished a master degree in human physiology, and I came to understand during my two years working in the laboratory that this repetitive and pedantic work was not for me. At the same time, aside from my studies, I had been working as a group teacher in physiology at the university and as a mathematics teacher for students at a vocational school. I very much enjoyed the teaching experiences, especially the relationships I developed with the students (contrary to the cells in the petri dishes). So after I graduated, I worked as a science teacher in upper secondary schools for eight years. I found the work exciting, fun, challenging, exhausting – but never boring. The combination of science as a subject matter and the social aspects of being a teacher suited me well. In Norwegian schools, practical work is seen as an important part of all the science subjects. Even though the Norwegian curriculum does not provide any prescription regarding type and frequency of practical work, it is considered an important part of science education. For example in the natural science subject in upper secondary school, at least one of five weekly lessons (each lesson lasting 45 minutes) is dedicated to laboratory work, while for the biology subject lab work is even more frequent. In addition, science teachers commonly use demonstrations in the laboratory and, less frequently, fieldwork outside school as part of the practice. The weight on *practical work* in the Norwegian school system might be seen as a parallel to school *science inquiry*, more commonly referred to in international research literature. From teaching science for eight years at upper secondary level, I found that the students enjoyed practical work, but they disliked writing reports, and the learning outcome was not always what it was intended to be. Moreover, I developed an *implicit* understanding of what worked and what did not work in the classroom in order for the students to learn from science inquiry. At the time, I was also teaching a group of biology students studying for the International Baccalaureate, whose curriculum placed more emphasis on essential features of scientific inquiry, including assessment criteria. This more *explicit* focus on scientific inquiry was not common practice in Norwegian classrooms at the time. I did my best to teach science inquiry using textbooks, my own experiences from lab and fieldwork, and input from more experienced science teachers. However, at the upper secondary school I used to work at, the group of twelve science teachers rarely reflected together on our inquiry practice and how to develop and improve it.

Several years later, after working in teacher professional development and teacher education for several years, I got the opportunity to work with school science inquiry for my Ph.D. To be honest, like many experienced science teachers, I felt that I knew a lot about inquiry from own practice in school. However, starting to read more international literature in the field, I was struck by the amount of research that has been produced in the last 50 years concerning science inquiry. For example in a review from 2012, Roth found that 592 out of the 6,294 articles in six major science education journals included the term “inquiry” as an identifier in the title or abstract. Given the relatively sparse literature available in Norwegian on the field, and the implicit way that science inquiry is handled in Norwegian schools when it comes to purpose, implementation and learning outcome, there seemed to be a long way to go in order to improve today’s practices. Moreover, it is not common for Norwegian teachers – perhaps because of time limits and other external barriers – to read educational literature to improve their practice. Thus, I valued the possibilities provided by the StudentResearch project using collaborative action research to develop and learn from practices of inquiry, taking advantage of teachers’ “personal practical knowledge” and researchers’ more theoretical knowledge. In the next section, I will provide some more information concerning the research project StudentResearch.

1.4 StudentResearch

The point of departure for the StudentResearch project was the implementation of the Norwegian curriculum reform Knowledge Promotion. The research project lasted from 2007-2011 and was started by the Norwegian Research Council as part of the research program PRAKSISFOU (2005-2010). The project was led by Professor Erik Knain, and was built on collaboration between the Norwegian University of Life Sciences (Professor Erik Knain), the University of Bergen (Professor Stein Dankert Kolstø) and the University of Oslo (Professor Ola Erstad). Moreover, six secondary schools have been part of the project. The following goal for the project StudentResearch is stated on the project’s wiki:

> Our goal is that the students will become knowledge builders in practices that will have some common traits with scientific research. This means that the students will get to know the creative, reflecting and communicative parts of science, and that they will develop knowledge about the characteristics of science in order to carry through experiments. ICT tools can contribute as an arena for knowledge building trough individual and collective processes as a part of basic skills as reading and writing. (StudentResearch, 2007)

StudentResearch included several projects in the Oslo region and in Bergen, having to some extent different goals and perspectives within the project’s overarching goal. The common approach for the individual projects was action research, aiming at developing and learning from classroom practices through collaborations between teachers and researchers. This study reports from the collaboration between a group of science teachers at an upper secondary school outside Oslo and two researchers, Erik and Birgitte, from The University of Life Sciences. Our common goal was to improve and learn from classroom practices of open inquiry.

We had several meetings in StudentResearch, some with teachers, school managers and researchers, and others with the research group consisting of three senior researchers, four Ph.D. students and several master students. These meetings provided a valuable arena for meaningful and challenging discussions from different perspectives on science inquiry in Norwegian schools. Moreover, the collaboration in the research group resulted in a textbook for teachers and teacher education, titled after the project: StudentResearch (Knain & Kolstø, 2011). Each of the book's chapters presents a central theme arising from across the individual projects. The book can be seen as important, as it is the first textbook written in Norwegian concerning science inquiry and based on empirical data from the Norwegian school context. I co-authored three of the chapters in the textbook: "Rammer og støttestrukturer i utforskende arbeidsmåter" [Frames and scaffolding structures in inquiry-based learning] (Knain, Bjønness & Kolstø, 2011); "Lærerens rolle ved utforskende arbeidsmåter" [The teacher role concerning inquiry-based learning] (Bjønness, Johansen, & Byhring, 2011) and "Vurdering ved bruk av utforskende arbeidsmåter" [Assessment as part of inquiry-based learning] (Kolstø, Bjønness, Klevenberg, & Mestad, 2011). It was a valuable and motivating learning process to collaborate with researchers and teachers to develop concepts, knowledge and principles concerning science inquiry in the Norwegian school system.

1.5 Outline of the extended abstract

The thesis is divided into two parts. Part I consists of the Extended Abstract, which includes six chapters. After the introduction, in *Chapter 2,* I will present a review of relevant research on scientific inquiry and NOS in school science, and point to some key issues concerning trends and challenges. In *Chapter 3,* a theoretical framework including the perspective of Dewey's experimental learning and the sociocultural legacy from Vygotsky will be presented. In *Chapter 4,* I will provide information about the school context, including the open inquiry project, and participants in the action research project. In *Chapter 5*, I will deal with methodological considerations. This includes the case study design and the action research approach. Moreover, methods for data collection in the field and an account of the data analysis are provided. Finally, the quality of the study and ethical considerations are discussed. In *Chapter 6*, a summary of the three articles in the thesis will be provided, and I will discuss the thesis as a whole and discuss implications for science teacher education and teacher professional development. Part II consists of three articles included in the thesis. The three articles are presented in the thesis according to the shifts of framing at three different levels.

2 Review of relevant research

In order to pursue the overarching research question guiding this study, I will focus the review around research on challenges teachers face in implementing and improving science inquiry in schools. I will begin the review by presenting a brief overview of the history of science inquiry in schools, and establishing what science inquiry is, and what it is not, for the purposes of this study. I believe these clarifications are necessary, taking into account the great variety of meanings and practices associated with the term *inquiry* in science education. Moreover, I will focus on research concerning teachers' implementation and improvement of science inquiry in schools, highlighting issues that are important for this study. Finally, I will point at some key issues enabling me to document the limitations of existing research and point out what can be gained through in-depth longitudinal studies of science inquiry in a situated classroom practice.

2.1 A brief history of school science inquiry

> [S]cience has been taught too much as an accumulation of ready-made material with which students are to be made familiar, not enough as a method of thinking, an attitude of mind, after the pattern of which mental habits are to be transformed.
> (Dewey, 1910/1964, p. 183)

More than 100 years ago John Dewey encouraged science teachers to include inquiry in their teaching practice (Dewey, 1910/1964). According to Dewey (1938), the teacher should provide students with opportunities to address problems they themselves are interested in. He proposed that the students must be active learners in searching for answers to connect problems with their experiences and within their intellectual capacity, while the teacher has a role as facilitator or guide (ibid.). Dewey's ideas on educative experiences and reflecting thinking have been used to advocate various forms of student-active learning, including inquiry-based learning. The legacy of Dewey is further elaborated in chapter 3.1.

In the USA and in Europe, inquiry-based learning and practical work have been a corner stone in science education for more than 50 years (e.g., Anderson, 2007; Hofstein & Kind, 2012). This is also true in the Norwegian context (Kind, 2003). In a review on school science laboratories, Hofstein and Kind (2012) found that when schools started to teach science systematically in the nineteenth century, the laboratory became important in science education. However, the laboratory was used mainly as a means for confirmation and illustration of facts learnt previously in a lecture or from a textbook; in many ways this was similar to the practice of laboratory in school science today (Tiberghien et al., 2001).

After World War II, the goal of science education was to develop students' capacity to think like scientists and prepare for careers in science (Duschl, 1990). Embedded in the "science for scientists" approach was the view that students should be given the opportunity to engage with natural phenomena and conduct inquires that would reveal the patterns of nature and the guiding conceptions of science (Duschl & Grandy, 2008). The goal was to downsize the role of the textbook and increase the role of laboratory experiences in science classrooms. According to Schwab (1962), school science should be designed as "enquiry into enquiry" and not only deliver the "facts" of science. With the curriculum reforms in science education in the 1960s, both in the USA and in the UK, the ideal was to engage students with investigations, discoveries, problem-solving activities and inquiry (Hofstein & Kind, 2012). Contemporary science education has moved from teaching what we know to teaching science as a way of knowing (Duschl & Grandy, 2008). However, science as a way of knowing is also moving away from a view that emphasises observations and experimentation to a view that stresses theory, model building and revision—in other words, a view that evidence is obtained from theory-driven observation. One of the questions arising is, then, the amount of time that should be allocated to interactions with basic scientific phenomena (ibid.).

The commitment to inquiry and science investigations is still a hallmark in science education. Moreover, recent results from international research indicate that students learning from inquiry-based teaching perform better than students in traditional courses (e.g., Blanchard et al., 2010; Furtak et al., 2012; Wilson, Taylor, Kowalski, & Carlson, 2010). However, many questions are still asked about the various forms of inquiry, efficiency and benefits (Anderson, 2007; Crawford, 2014; Hofstein & Kind, 2012). In the next section I will make some clarifications concerning school science inquiry and delimitations for this study.

2.2 Inquiry in school science – what is it?

Inquiry is a major field in science education, and this is reflected through the extensive and comprehensive research that has been conducted on this theme all over the world (Anderson, 2007; Crawford, 2014; Hofstein & Kind, 2012). The present study is about *open inquiry* in the science classroom, in which the main goal for the classroom practice was the understanding of some essential features of NOS and scientific inquiry. Therefore, I will start by defining key issues concerning NOS and scientific inquiry in the classroom. Then I will present some dimensions of inquiry in the science classroom and place the present study within this landscape.

2.2.1 Learning about NOS and scientific inquiry in school science

Students' and teachers' understanding of NOS has a high priority in science education and science education research. At a general level, understanding of NOS has been suggested as a critical component of scientific literacy (Lederman, 2007a; Osborne, 2007). Driver, Leach, Millar, and

Scott (1996) offer five arguments for the importance of understanding NOS: *Utilitarian* – to make sense of science and to manage technological objects and processes in everyday life; *Democratic*—to make informed decisions on socio-scientific issues; *Cultural*—to appreciate the value of science as part of contemporary culture; *Moral* – to develop an understanding of the norms of the scientific community that embody moral commitments; *Science learning* – to facilitate learning of science subject matter. In The Second International Handbook of Science Education, Norman Lederman and Judith Lederman (2012) provide an understanding of NOS and scientific inquiry that have been shown in empirical studies to be understandable by secondary students. They suggest the following characteristics of *NOS* in science education (p. 336):

- scientific knowledge is tentative (subject to change);
- empirically based (based on and/or derived from observations of the natural world);
- subjective (involving personal background and biases and/or being theory-laden);
- necessarily involves human inference;
- imagination and creativity (involving the invention of explanations);
- and socially and culturally embedded.

Moreover, Lederman and Lederman provide an understanding of *scientific inquiry* considered to be appropriate and understandable for secondary students (2012, p. 339):

- scientific investigations all begin with a question, but do not necessarily test a hypothesis
- there is no single set and sequence of steps followed in all scientific investigations
- inquiry procedures are guided by the question asked
- all scientists performing the same procedures might not get the same results
- inquiry procedures can influence the results
- research conclusions must be consistent with the data collected
- scientific data are not the same as scientific evidence
- explanations are developed from a combination of collected data and what is already known

However, these characteristics of NOS and scientific inquiry are not necessary easily translated into classroom practice. Many teachers will argue that it is a rather difficult undertaking. This may be one of the reasons why the practice of science inquiry in school seems to be dominated by oversimplified versions of scientific inquiry that do not represent a contemporary understanding of NOS and scientific inquiry (Duschl & Grandy, 2008; Windschitl, 2004). Moreover, Lederman and Lederman (2012) found in an analysis of several long-term professional development courses about NOS and scientific inquiry that most teachers believed that students could learn NOS only by *doing science*.

Change might be difficult to effect in the classroom since many science teachers do not possess adequate understanding of NOS (Abd-El-Khalick & Lederman, 2000; Lederman, 2007a;

McComas, Almazroa, & Clough, 1998). It appears from research that a positivist ideology is commonly held among science teachers (Bryan, 2012; McComas et al., 1998). Furthermore, some research suggests a congruency between a teacher's beliefs and his or her practice (e.g., Bencze et al., 2006), while other show no significant relationship (e.g., Kang & Wallace, 2005). In an analysis of student teachers developing their own empirical investigations, Windschitl (2004) suggests that the students hold tacit framework of what it means to "do science" that shapes their practices and influences their reflections on their inquiries. The student teachers' views appear according to the author to be consistent with a "folk theory" of doing science that is promoted in textbooks, through the media, and by members of the science education community themselves. Research also reveal that in the rough and tumble of practice, teachers focus on what works in terms of student involvement or classroom management and not on theoretical knowledge (Anderson, 2007; Hodson & Bencze, 1998). This means that teachers struggle to implement inquiry in the classroom consistent with reform documents and contemporary views of scientific inquiry (Bencze et al., 2006; Crawford, Zembal-Saul, Munford, & Friedrichsen, 2005; Windschitl, Thompson, & Braaten, 2008).

In a review on NOS in science education, Lederman (2007a) found that most research done on NOS has been relatively superficial, in the sense of an "input-output" model, and that little is known about in-depth mechanisms that contribute to change in teachers' and students' views. However, more resent research is moving toward the reality of the daily classroom practice (Crawford, 2014). The next section provides an introduction to the Norwegian curriculum and the focus on NOS and scientific inquiry.

2.2.2 NOS and scientific inquiry in the Norwegian curriculum

The understandings of NOS and scientific inquiry for science education found in the Norwegian curriculum are emphasised at several levels. The Norwegian core curriculum (Ministry of Education and Research, 1994), which constitutes a binding foundation for the development of the separate subject curricula, states that:

> Education shall not only transmit learning; it shall also provide learners with the ability to acquire and attain new knowledge themselves (…). The aim of education is to train pupils in both synthesis and analysis—to develop both imagination and scepticism so that experience can be translated into insight. Scientific method develops both the creative and critical senses, and is within everyone's reach. (p. 14).

The core curriculum reveals a focus on the active and autonomous pupil, and the role of scientific inquiry. Moreover, in the Norwegian natural science curriculum (Ministry of Education and

Research, 2006), a subject area has been formulated called “the budding researcher” that focuses explicitly on NOS and scientific inquiry:

> The budding researcher shall work with the dimensions of processes in natural science such as methodologies for developing science. This involves the formulation of hypothesis, experimentation, systematic observations, openness, discussions, critical assessment, argumentation, grounds for conclusion and presentation. (p. 2).

The competence goals for “the budding researcher” after year 11 states that the pupils shall be able to:

- plan and carry out different types of investigations in cooperation with others in which they identify variables, estimate uncertainties of measurements and assess possible sources of errors
- carry out and interpret animations and simple computer simulations to illustrate natural phenomena and test hypotheses
- explain and assess what can be done to reduce uncertainties of measurements and avoid any possible source errors from measurements and results
- assess the quality of presentations of their own and others’ observation data and interpretations

The subject area “the budding researcher” is supposed to be integrated into the other five subject areas in natural science. In addition, the basic skills formulated for the natural science subject have several goals in common with the goals of “the budding researcher”. For example, the basic skills “being able to express oneself orally and in writing” means:

> [P]resenting and describing one's own experiences and observations from nature. In the natural science subject, written reports from experiments, fieldwork, excursions and technological development processes are an important part of the work. This includes the ability to formulate questions and hypotheses and to use natural science terms and concepts. Arguing for one's own assessments and giving constructive feedback is important in the natural science subject. (p. 4)

Thus, students’ understanding of NOS and scientific inquiry have a central position in the Norwegian curriculum, both in the core curriculum emphasising scientific literacy, and in the natural science subject. In the next section some of the diversity of inquiry in the science classroom will be presented, and I will place the present open inquiry approach in this landscape.

2.2.3 Versions of inquiry in science classrooms

There is a lack of agreement of what entails inquiry in the science classroom (e.g., Barrow, 2006; Crawford, 2014). In an international study comparing research on school science inquiry, Abd-El-

Khalick and his co-authors (2004) found images of inquiry ranging from structured laboratory-activities-with-a-twist, to poorly structured approaches for generating evidence-based answers to ill-defined questions. Moreover, the use of the word "inquiry" in science education is imprecise; as stated by Anderson, "[…] it is a bit like using the word *romance* in a conversation about human relationships. It has different meanings in varied contexts, and it is hard to guess what particular meaning a given speaker has in mind when the word is used" (2007, p. 808). Thus, a clarification concerning the use of "inquiry" is necessary in every case.

There are, roughly speaking, two main strands of science inquiry found in schools: science inquiry as a *means* to learn science, and science inquiry as an *end* in itself (Abd-El-Khalick et al., 2004; Asay & Orgill, 2010). Science inquiry as a means refers to designed experiences and activities that lead to knowledge and understanding of scientific ideas and content (Asay & Orgill, 2010). Inquiry as an end is described the following way by Abd-El-Khalick and co-authors:

> "Inquiry as ends" (or inquiry *about* science) refers to inquiry as an instructional outcome: Students learn to do inquiry in the context of science content and develop epistemological understandings about NOS and the development of scientific knowledge, as well as relevant inquiry skills. (Abd-El-Khalick et al., 2004, p. 398)

The type of science inquiry that is found in the present study is the version in which the goal is science inquiry as an *end,* meaning the "doing" of inquiry in addition to learning scientific inquiry as content. Moreover, the present study concerns *open inquiry*, in which the students are given the opportunity to choose both the question and the design for the inquiry. Numerous researchers have suggested that this version of inquiry can enhance more *authentic science learning* (Duschl & Grandy, 2008; O'Neill & Polman, 2004; Roth, 2012; Wells, 1999). The meaning of authentic science learning in the present study follows an understanding provided by Roth (1995) suggesting that authentic practices in school involve activities that resemble with the activities in which core members of the research community actually engage.

However, versions of science inquiry in the classroom are diverse and do not necessarily fall into the simple categories of means and end. The different types of inquiry can also be ranged by openness, complexity, planned learning outcome and level of teacher guidance, among other factors. In order to place the present study in an inquiry landscape, I will use an overview revealing how different levels of complexity put constraints on the learning outcome and teacher guidance (Table 1). The table was developed in StudentResearch and presented in an article about socio-scientific issues (Albe et al., 2014, p. 64).

Table 1. How issues with different levels of complexity in general put constraints on the openness in planned learning outcomes and the adequate level of teacher guidance.

Complexity of issue	**Typical issues dealt with**	**Typical learning outcome**	**Characterisation**
Low	Scientific concepts (e.g., laws of electromagnetic radiation and its effect on cells)	Scientific concepts and scientific reasoning	Teacher-guided inquiry toward correct explanations
Intermediate-low	Scientific laws (e.g., how to calculate and measure electromagnetic radiation)	Scientific methodology (e.g., control of variables, practical skills, scientific concepts, scientific reasoning)	Half-open inquiry toward well-known empirical relations
Intermediate-high	Technology quality (e.g., comparing air and dug-down power lines)	Scientific methodology (e.g., identification of variables, practical skills, scientific concepts, scientific reasoning)	Open testing toward loosely defined learning outcomes
High	Socio-scientific issues (e.g., what to do with power lines through residential areas)	Handle disputed claims, collect, examine and integrate information in cooperation, relevant scientific concepts	Open inquiry toward personal judgments

The table reveals how the teacher needs to plan for different types of inquiry depending on the complexity of the issue and the expected learning outcome. In Norwegian science classrooms, conducting a “recipe” experiment with *low complexity* is a common way of performing inquiry. However, the students are not encouraged to ask their own questions during such activities. According to Högström, Ottander, and Benckert (2010), who studied Swedish secondary students’ interaction during lab work, the students did not ask questions other than those already given by the teacher and the manual. Open inquiry is suggested as an opportunity for students to perform their own inquiry and ask their own question. The present inquiry project is characterised by *intermediate to high complexity* and a typical learning outcome of *scientific methodology*.

The table above is not very precise concerning the levels of *teacher guidance*. According to Crawford (2007), the activities in open inquiry are typically more student-directed compared to more structured forms of inquiry, in which the activities are more teacher-directed. The relationship between the students and the teacher will always remain asymmetric, but during open inquiry the students will become more *autonomous* in their learning (ibid.). In the present study, *autonomy* means that the students, to a large extent, act according to their own interests and abilities, and that they gradually take more responsibility for their own learning in the project. The teacher encourages the students “to be authors and producers of knowledge, with ownership over it, rather than mere consumers of it” (Engle & Conant, 2002, p. 405). In any circumstances, the amount and form of teacher guidance depends very much on the learning environment, including students, teachers, school culture, laboratory facilities and so on.

2.2.4 Open inquiry – is it possible to achieve in a science classroom?

The learning outcome and value of open inquiry is very much debated. Defenders of open inquiry claim that students learn how science operates from formulating their own research design, generating, analysing and interpret data, and reporting results. These activities are supposed to make the students more likely to develop some of the practice-based competences that are useful in everyday and policy decisions, as well as in the practice of science (O'Neill & Polman, 2004; Roth, 2012; Zion & Slezak, 2005). Open inquiry is also suggested as a way to provide opportunities for students to experience the complex and uncertain nature of scientific inquiry, counteracting the idea of a simplified step-by-step method represented by the commonly found recipe versions (O'Neill & Polman, 2004). It is as well valued as an opportunity for students to experience the social nature of scientific work and knowledge (Wells, 1999). Furthermore, open inquiry is proposed as a means to enhance active and autonomous learning, providing opportunities for students to engage in activities to which they are committed, and promoting a positive attitude toward science (Hodson, 2009; Wells, 1999).

However, the science education community disagrees as to whether students are capable of engaging in "authentic" scientific inquiry, and whether the child can be seen as a "little scientist" (e.g., Brewer, 2008; Duschl & Grandy, 2008). Some question whether students actually have the knowledge and skills to engage in open inquiry, and if teachers have the experience and knowledge necessary to scaffold their students during open inquiry. There is also a question whether the complexity of open inquiry is too difficult for students to handle and too demanding for teachers to scaffold. Open inquiry has been criticised as an inadequate representation of scientific inquiry, and, moreover, an unsound teaching approach. According to Settlage (2007) there is a myth that open inquiry is on the top of the hierarchy of teaching approaches. "[…] [H]olding open inquiry as the purest form of classroom inquiry and suggesting it is an ideal for which science teachers should strive is a myth", he writes (p. 464).

However, some educational literature reveals that a number of teachers are successfully engaging their students' learning from open inquiry (e.g., Crawford, 2007; O'Neill & Polman, 2004; Zion & Slezak, 2005). For example Sadeh and Zion (2009) compared open inquiry versus guided inquiry for high school biology students and found that the group of students performing open inquiry demonstrated significantly higher levels of performance on the criteria "changes during inquiry" and "procedural understanding". The results also indicated significant difference in the criteria "learning as a process" and "affective points of view". In a study by Yerrick (2000) on the effect of open inquiry with low-achieving high school students, the students were asked to participate in question generation, experimental design and argument construction. The students' argumentation after the open inquiry revealed a shift toward NOS, including "students' tentativeness of knowledge claims", "students' use of evidence", and "students' views regarding the source of scientific authority". Thus, some studies indicate that it is possible for diverse students to learn essential features of scientific inquiry and NOS by engaging in open inquiry. However, this success is naturally dependent on the teacher scaffolding of the activities, and there are many reports on how teachers and student teachers lack the experience and knowledge on how to support students during their inquiries (e.g., Lederman & Lederman, 2012; van der Valk & de Jong, 2009; Windschitl et al., 2008). This leads us to the next section about teachers' support of open inquiry.

2.2.5 Teachers' support of students learning from open inquiry

In order to include open inquiry in science education, an important question is how the teacher can create a classroom environment in which students are more self-directed when they engage in inquiry (Zion & Slezak, 2005). In research literature, student-centred approaches are often claimed to be unguided or minimally guided, making them less efficient than instructional approaches (Kirschner, Sweller, & Clark, 2006). The critique has been answered by, amongst others, Hmelo-Silver, Duncan and Chinn (2007), who argue that inquiry-based learning and problem-based learning are scaffolded extensively.

It is perhaps more purposeful to ask what type of scaffolding is appropriate to serve the intended learning goals of open inquiry. Hodson (2009) suggests that "Too much guidance can interfere with students' thought processes, act to frustrate problem solving and lead to premature closure; too little guidance can leave students unable to make satisfactory progress and lead to feelings of frustrations, and even alienation" (p. 213). Thus, there needs to be some kind of balance between *space* for students to express their own ideas and tentative understanding (Wells, 1999), and *structure* that scaffolds essential features of scientific inquiry (Asay & Orgill, 2010). Although there are examples in the literature of teacher guidance and scaffolding of open inquiry (e.g., Crawford, 2000; van der Valk & de Jong, 2009; Windschitl et al., 2008; Zion & Slezak, 2005), few of these address how the teacher's scaffolding influences the students' learning process during open inquiry. A contextual understanding of how a teacher's actions influence the nature of students' inquiry processes is important (Blanchard et al., 2010), knowing that the form of scaffolding depends on the nature of the learning task, the particular students involved and the specific educational context (Saye & Brush, 2001).

In the Norwegian school context, the PISA report from 2007 (Kjærnsli, Lie, Olsen, & Roe, 2007) showed that engaging students in science inquiry did correlate negatively with achievement; however, the report did not distinguish between the great variety of inquiry approaches that exist in schools. One of the authors of the PISA report, Olsen (2013), discusses what implications these result might have for science education, suggesting that inquiry-based teaching is a step in the wrong direction. The author also proposes that inquiry is activity without support, guidance and structure. This critique is probably not well founded; several research projects with empirical data from Norwegian primary schools (Ødegaard et al., in press) and upper secondary schools (Knain, Bjønness, & Kolstø, 2011) reveal that various forms of inquiry are not necessarily “laissez-faire”, but on the contrary are often highly scaffolded. However, we are still in need of more knowledge about science inquiry in the Norwegian classroom to continually improve practice, and to build our knowledge on a solid contextual understanding.

Crawford (2014) found in her review of research on school science inquiry a movement away from simply debating if inquiry is “good”, and toward trying to identify the characteristics of inquiry found in the science classrooms. Research underlines the importance of the teacher in actively guiding students during inquiry. Educational researchers are now focusing more on answering questions like, “How can inquiry be successfully enacted in schools?” They examine how barriers, both external (e.g., the school context and school culture) and internal (teacher knowledge, beliefs and views) have implications for teacher education and professional development. It is in this landscape that the present thesis is grounded. Article I explore in depth a science teacher’s beliefs about NOS and open inquiry in a situated school practice. Article II seeks to explore and understand a teacher’s support of open inquiry in a classroom setting with all its complexity, and how it influence students learning process. Finally, Article III discusses the possibilities and challenges of developing science inquiry practices through collaborative action research.

3 Theoretical background

In this chapter I will present literature representing the legacy for school science inquiry we build on today, namely John Dewey's theories on experience and reflecting thinking. Moreover, I will present some of the ideas of Lev Vygotsky and sociocultural theory, both of which are important for the understanding of how science can be learned and have consequences for practice of school science inquiry. Both theories contribute to a platform that can help us understand science inquiry through a situated school practice.

3.1 John Dewey on education

Drawing on Dewey's ideas about education serves three purposes. His vision of educative experiences and its legacy to science inquiry provides a theoretical perspective. His ideas about the differences between traditional and progressive education are much the same as views today on this topic, and Dewey's ideas can also be seen as a foundation for action research.

3.1.1 Experience and reflecting thinking—the legacy of Dewey

John Dewey's ideas about education (Dewey, 1938) have been used to advocate various forms of student-active learning, including problem-based learning, inquiry-based learning, laboratory work and outdoor schooling (Wong & Pugh, 2001). In a historical analysis reviewing 60 years of the journal 'Science Education', Champagne and Klopfer (1977) found that every theory and practice that emphasised reflective thinking and problem solving owe a debt of gratitude to Dewey. However, they also found that some of Dewey's core ideas seem to have been lost in translation from philosophy to practice and that his vision failed to be realised in actual classrooms (ibid.).

Perhaps the most central idea in Dewey's vision for education is the notion of "experience". However, he did not believe that every experience was valuable to education, claiming that everything depends upon the *quality* of an experience. Soltis (2002) uses a simple example to explain Dewey's thinking about an educative experience: When a child reaches for a candle flame and he burns his hand, he experiences pain, but this is an educative experience only if the child realises that touching the flame resulted in a burn, and he formulates a general expectation that flames will produce burns if touched. This natural form of learning from experience by acting and reflecting on the results of these actions was central to Dewey's vision for education. The central problem of an education based on experience was, according to Dewey (1938), to select the kind of experience that would live fruitfully and creatively in subsequent experiences. In "Art as Experience" Dewey describes educative experiences:

> A piece of work is finished in a way that is satisfactory; a problem receives its solution; a game is played through; a situation, whether that of eating a meal, playing a

> game of chess, carrying on a conversation, writing a book, or taking part in a political campaign, is so rounded out that its close is a consummation and not a cessation. Such an experience is a whole and carries with it its own individualising quality and self-sufficiency. It is an experience. (Dewey, 1934, p. 35)

Dewey (1938) formulated two main principles of experience: *continuity* and *interaction*. The principle of *continuity* reveals how any experience affects, for better or worse, the attitudes that help determine the quality of further experiences. According to Wong and Pugh (2001), Dewey relies on the notion of anticipation as the "intellectual and emotional energy that both drives and holds together the development of an experience" (ibid., p. 321). To exemplify this, I will refer to the present case of open inquiry in which the students got the opportunity to choose ideas that were interesting and relevant for them to explore.

> One of the students groups wanted to compare the quality of bottled water with tap water since so many students at the school had the habit of buying bottled water. The students formulated a hypothesis claiming that tap water was less healthy than bottled water. Furthermore, they considered several methods to test their hypothesis; conferring with the teacher, reading relevant documents and taking into consideration the equipment available at the school lab. Finally, they decided to compare bacteria growth, pH, salt and transparency of the water samples. They worked relatively independently with the inquiry, but received some support from the teacher and other experts, especially in order to perform the tests and interpret the results. The students got quite a lot of attention when they found that bottled water actually contained more bacteria than the tap water at the school.

This example can be characterised as an experience where the anticipation of what might be the result acted as a driving force for these students, connecting the parts of the inquiry (continuity) and moving it forward. In contrast, a lab activity following a recipe is, in light of Dewey's thinking, not an educative experience even though students are active and there is experience, since it lacks the unfolding drama of inquiry in which one part leads to the next (Wong & Pugh, 2001).

According to Dewey, the teacher's responsibility is to organise the conditions of the experience using his or her wider experience without imposing merely external control. This calls for teachers being able to understand individual students and what is going on in their minds. Moreover, Dewey proposed that teachers should above all utilise their surroundings, physical and social, to extract from them what they have to contribute to build up experiences that are worthwhile. However, Dewey also focused on the experiences of experts as important components of an experience. This leads to the second chief principle in an experience: *interaction*. According to Dewey, any normal experience is an interplay between two sets of conditions: objective and internal. The experience exists as a transaction between an individual and what constitute his or her environment. This can be illustrated by an example from the case above: the students were *interacting* with the local department responsible for healthy drinking water, and they got help from experts to interpret the tests they had done in order to understand their results in a relevant explanatory frame.

Dewey's concept of education as experience does not mean rejecting all authority; on the contrary, basing education upon personal experiences may mean more multiplied and intimate contacts between the students and the teacher, and thus rather more than less guidance by others. Dewey rejects the idea of proceeding as if any form of direction or guidance by the teacher or other adults were an invasion of the student's individual freedom. Dewey saw education as essentially a social process. He proposed that the teacher, as the most mature member of the group, is responsible for interaction and intercommunity of the group. Thus, the teacher loses the position of external boss, but takes on that of leader of group activities. Dewey described in "Experience and Education" the nature of freedom and structure:

> [T]here should be brief intervals of time for quiet reflection only when they follow after time of more overt actions and are used to organise what has been gained in periods of activity in which the hands and other parts of the body besides the brain are used. (Dewey, 1938, p. 63)

Dewey held the scientific method as an ideal model of an educative experience. He realised that the open attitude, careful experimentation and critical reflection of scientific inquiry make its knowledge claims strong (Won, 2010). His view of the scientific method as "a working pattern of the way in which and the conditions under which experiences are used" (Dewey, 1938, p. 88) may be criticised today in that there is no "one scientific method" (Giere, Bickle, & Mauldin, 2006). However, according to Won (2010), Deweyan scholars find the interpretation of his view as positivistic to be ironic, claiming that he opposed it from the start. This misinterpretation can be explained by looking at the difference between Dewey's view of inquiry and the views of those who responded to his call and put inquiry on the curriculum (Tanner, 1988).

Moreover, Dewey did not believe that students could study scientific facts and principles in the ways an expert studies them. On the contrary, he emphasised that one of a teacher's main problems was how to present experiences so that students can gradually be led through extraction of facts and laws, to experience scientific order. Dewey was concerned with *the experimental method of science* claiming that it pays more attention to ideas than do other methods. Wong and Pugh (2001) underline that Dewey would not value an idea simply because it was student generated; the value of an idea lies within what is meaningful in the world of the young. This was what Dewey meant by student-centered learning—and why ideas are educative only if they inspire action.

Articles I and II in this thesis concern open inquiry in the science classroom, and Dewey's theoretical perspective of what constitute an educational experience is fundamental to understand the possibilities and constraints from open inquiry. Moreover, his ideas on the teacher's role in interacting with students are of special interest, providing an understanding of the importance of the relationship between the teacher and the individual student. This includes the idea that the teacher can organise the students' experiences without imposing merely external control. In Article III, we discuss change of inquiry practice in school through action research. Dewey's ideas about inquiry provide a fundament for action research. In addition, Dewey provides relevant perspectives on the process of how traditional education changes into more progressive education. In the following sections I will briefly present Dewey's thoughts on progressive versus traditional education, and his legacy to action research.

3.1.2 Progressive versus traditional education

Dewey paints a picture in Experience and Education (1938) of what the traditional school was like around that time he wrote the book. According to Dewey the chief business of school at that time was to teach subject matter worked out in the past, moral training to form habits in conformity with rules and standards of conducts, and "patterns of organisation"—meaning time schedules, examination and rules of order. Dewey claimed that these characteristics fixed the aim and methods of instruction and discipline. He criticised how the textbook was used as the chief representative of the lore and wisdom of the past, and how teachers were the agents through whom pupils were connected with the subject matter. His criticism of the traditional scheme was the imposition from above and from outside. I wonder, looking into Norwegian schools today, if those characteristics arising more than 70 years ago are so distant after all. International research revealing how science is taught in school today show that it still reflects a traditional school culture (Sarason, 1996), in which schools are struggling to implement ideas such as science inquiry (Barrow, 2006; Windschitl, 2002).

Certainly, scientific inquiry is complex and difficult for the teacher to perform (Anderson, 2002; Crawford, 2007). Dewey himself was also clear on the point that an educational system based on living experience depends on the teacher's ability to understand the students and to become intimately acquainted with, for example, the local community is difficult to achieve (Dewey, 1938). He acknowledged that to work out materials, methods and social relationships that are appropriate for experiential education is much more difficult than the case with traditional education.

Another question that arises as a consequence of Dewey's ideas about inquiry is: When students have freedom to investigate their own experiences and ask their own questions; how can teachers actually teach the required curriculum and its body of knowledge? The teacher might stand in a difficult position, caught between imposing established scientific knowledge on the students and snuffing out their initiatives, or basing teaching on students' ideas and risking that they will not learn the science necessary to make their inquiry scientific. According to Dewey, it is the teacher's responsibility to find a subject within the students' experiences and draw the link to the learning of science (Won, 2010). Dewey did not recognise the school science subject matter as a fixed, ready-made entity itself, but as flexible enough to be organised in different ways for various pedagogical and educational purposes (ibid.). An interesting point is that the dilemmas revealed here are very much the same as when we discuss school science inquiry today. Windschitl (2002) proposes that Dewey's attempts at progressive schooling faced challenges for teachers that resemble those of today:

> Creating and adapting curricula to meet the needs of learners, managing more active classrooms, and dealing with accountability issues regarding student learning. Such conditions, then as now, have often overwhelmed educators. (p. 134)

Thus, there still exist many concerns related to the progressive form of education connected with inquiry-based learning, regarding both the creation of relevant curricula and their implementation in the classroom.

3.1.3 Dewey's ideas as a foundation for action research

Action research as an approach for change and development inside schools is proposed as a response to failure by outside experts to bring about planned change in schools (Herr & Anderson, 2005). Moreover, Dewey's ideas about inquiry, in which rational thought is interspersed with action, have been put forward as a key premise for action research (e.g., Helskog, 2014; Lewin, 1948). According to Baskerville and Myers (2004), Dewey proposed that inquiry involves two kinds of operations: ideational (reasoning) and practical (action). Reasoning can provide the means for change, but only action, directed by reasoning, can effect change (ibid.). Dewey's view on the relation between ideas and empirical data, and between theory and practice, has influenced and justified action research from the beginning (Helskog, 2014).

3.2 Sociocultural perspective to learning—a Vygotskian framework

According to Leach and Scott (2003), there are two main strands of learning theory that tend to be drawn upon in science education. The first one is the theory of "*conceptual change*" built on the legacy of the developmental psychologist Jean Piaget. The theory of conceptual change put weight on the necessity of understanding the knowledge students bring to a teaching situation, and of building teaching atop this knowledge. Educational literature following this tradition provides detailed descriptions of students' pre-instructional knowledge in science topics, and how knowledge changes as a result of teaching. It can be seen as an individual view of learning in science education (ibid). The second strand is the *sociocultural perspectives* that draw on theoretical foundations provided by the developmental psychologist Lev Vygotsky. One of Vygotsky's legacies is the idea that learning involves a passage from social contexts to individual understanding (Vygotsky, 1978). First we meet new ideas in social situations where ideas are rehearsed between people through talk, gesture, text and material tools; these interactions exist on a *social plane*, according to Vygotsky (Scott, Asoko, & Leach, 2007). In education this might, for example, reflect a classroom dialogue during which the teacher presents a concept for the students. When ideas concerning the concept are explored on the social plane, each student reflects on it and makes individual sense of what is being communicated. Moreover, the words, gestures and images used in the social exchanges provide the very tools needed for individual thinking. Thus, there is a transition from *social* to *individual* planes, whereby the social tools for communication become *internalised* and provide the means for individual thinking (ibid.). The teacher's role is to make scientific knowledge available on the social plane and support students as they try to make sense of it. In the past few decades, there has been a shift from viewing meaning-making in terms of cognitive processes in the individual, toward how the individual learns in social contexts (Leach & Scott, 2003).

The perspective of sociocultural learning versus a more individual view of learning in science education has important implications for teaching science inquiry. Leach and Scott (2003) express concern about practical work based on an underlying view of learning science as a process in which individuals change their ideas in response to mainly perceptual information. According to the authors, this can easily lead to school practices that have students do a lot of activities, with weak links between what the students observe and the scientific idea behind the activities. This separation of teaching scientific knowledge and the process of scientific inquiry is often found in science classrooms (Abrahams & Millar, 2008; Tiberghien et al., 2001).

In a sociocultural view of learning, language is regarded as the "master tool"—the tool that mediates the learning of all other tools (Wells, 1999). This means that language is not only a tool for social action, but also for what Vygotsky (1978) called "inner speech", to mediate individual mental activities like memory, thinking and reasoning. A sociocultural view of learning through science inquiry put forward the important role teachers have in guiding the students inquiry in such ways that the students interact with *ideas*, as much as the *phenomena* themselves (Hodson, 2009; Leach & Scott, 2003; Wells, 1999). This can be a teacher introducing scientific ideas and controlling the 'flow of discourse' (Mortimer & Scott, 2003) in the classroom to make scientific knowledge available on the social plane, or it can be students working in small groups during science inquiry getting support from the teacher to connect their thoughts and actions with the language and material tools of a discipline-community (Nersessian, 2008).

In the present case of open inquiry, with the aim of learning about scientific inquiry and NOS, students are involved in activities that resemble the activities in which core members of the research community actually engage (Roth, 1995). In this context, a sociocultural orientation depends upon the teacher making available mediating tools, expertise, knowledge and practices of a science community for the students (Brown et al., 1993). The tools that are used by the members of a science community can be grouped into material tools (e.g., data loggers, pH-meters, plants) and semiotic tools (e.g., text, talk, signs). These tools are inextricably linked to each other; for instance, when the students measure pH in a solution, their understanding depends on knowledge about measuring units, signs, and linguistic and symbolic conventions (Säljö, 2001). The students first encounter these cultural tools though joint activities assisted by the teacher; gradually they are supposed to master the practice in which the tools are used, and they become resources for individual mental activity. The final step occurs in further action, when the student makes use of the new function to participate in a similar social activity (Wells, 1999).

The three articles in the present thesis make use of concepts drawn from the sociocultural perspectives of Vygotsky's ideas. Article II concerns the teacher's scaffolding of his students' learning from open inquiry. Vygotsky brought the activities of teaching and learning together through his concept of the "*Zone of Proximal Development*" (ZPD) (Vygotsky, 1978). The ZPD is widely used by researchers and educators, providing a measure of the difference between what a student can achieve working alone and what he or she can achieve with assistance from a knowledgeable teacher or peer. The key point here is that the student's learning is conceived of as being directly connected to, and dependent upon, the supporting activity of the teacher on the social plane (Scott et al., 2007). The metaphor "*scaffolding*" is often used in a sociocultural perspective to describe the teacher's role supporting students' learning. According to Wells (1999), scaffolding can be seen as a way to operationalise Vygotsky's concept of "working in the zone of proximal development". The term is adapted from the work of Wood, Bruner and Ross (1976) on mother-child interaction. In their work, scaffolding originally described a tutorial process in which "an adult or 'expert' helps somebody who is less adult or less expert" (p. 89). In the context of a school, this can be a teacher adjusting the complexity of a learning task so the students can engage in activities that would be beyond their unassisted efforts (Bliss, Askew & Macrae, 1996). In contemporary educational literature, the ZPD is also used to describe collaborative activities. The ZPD is then seen as being created in the interaction between students participating in a joint activity, and the spirit of collaboration during inquiry motivates the activities in which the students engage (Wells, 1999).

In Article I and II, the sociocultural perspective is important in order to understand a teacher's complex beliefs and practice of science inquiry in a classroom (Keys & Bryan, 2001; Wells, 1999). Keys and Bryan propose that a sociocultural lens can be valuable applying it to

> [R]esearch on inquiry-based instruction by examining how teachers implement inquiry within the cultural context of their local situations, and how tools, language, and social organisations are used by teachers and interpreted by students. (2001, p. 633)

Finally, in Article III, some theoretical perspectives from Vygotsky, especially *tools* and *multi-voice*, (Cole & Engeström, 1993), are used to explore how the distinguished voices of teachers and researchers complement each other when they develop tools for a situated practice, and might act to bridge the gap between practice and research of science inquiry. These concepts are thoroughly described in Article III.

4 The empirical context

The three articles presented in this thesis are all based on a case study focusing on an action research project situated at Dale Upper Secondary School. In the following I will first present the school context and the open inquiry project. Then I will introduce the teachers and researchers collaborating in the action research project, along with the teacher Amir and his students.

4.1 The school context

> 14 students and 12 empty desks. The class has started five minutes ago and the students continue to move slowly into the classroom. One fourth of the students do not show up at all. Some are sitting in small clusters chatting, and some seem to be asleep; partly lying on their chairs not bothering to take off their outer clothes.[...]. The teacher starts introducing the task and they listen for some minutes. Very soon after they are on Facebook showing pictures to each other. The classroom environment is characterised by a continuing alternation between the school tasks, chatter, toilet visits etc. (My field notes, 26.01.2010)

The excerpt is drawn from field notes from a lesson with a group of students taking their final year of compulsory science at a Norwegian upper secondary school. The context of the case study is an upper secondary school located nearby Oslo, which will be called Dale Upper Secondary School for the purposes of this study. In the school year 2009–10, there were approximately 450 students and 100 teachers at the school. The school is located in an urban area of Norway, offering mostly vocational education programs, and some programs for general studies. There were two main reasons for choosing this school. *Firstly*, the school was regarded as a low status school amongst young people in the school district, and it struggled with a high drop-out percentage (in 2009–10 almost 40% of the students did not complete their studies). In this situated school context, the science teachers were struggling to improve their practice in order to engage students with low self-esteem and a lack of motivation for more academic subjects. *Secondly*, the school wanted to be part of the action research project, and the science teachers were willing to share thoughts and ideas, and to open up their classrooms.

The collaboration between Dale Upper Secondary School and the Norwegian University of Life Sciences started in 2005 through a teacher network including nine schools participating in a teachers' professional development program on the practice of ICT in the natural science subject. Furthermore, the collaboration between the school and the university continued through the present action research project in the period from 2007–2010. Our project's two researchers, Erik and I, collaborated with a core group of three science teachers to develop a practice of open inquiry at the general studies. A more detailed account of the process of action research project is presented in Chapter 5.2.

4.1.1 The open inquiry project at Dale Upper Secondary School

One of the science teachers at the school, Amir, had developed an open inquiry project that he had implemented for several years in his science classes. He told the other science teachers enthusiastically about how the open inquiry created interest for science amongst the students with low self-esteem in academic subjects like science.

The students at Dale Upper Secondary School can be described as low to medium achievers in science, and quite a lot of the students were reported by their teacher to have low competence in basic skills like writing and reading. Moreover, I observed during the three years at the school that it was quite common for students to skip school, arrive late and “forget” homework. The students did not misbehave; most of them just seemed very uninterested in school. At another upper secondary school in the district with similar problems, Johansen (2013) found that the teacher responded to students’ low expectations of what a science class would be like by providing simplifications and low-challenge communication. Moreover, during inquiry the students were provided with collaborative freedom combined with step-by-step procedures. This type of simplification is also seen in international research in school contexts with low-achieving students. For example, instead of opening up classroom talk, teachers use strategies to limit students’ input by directing and constraining their contribution, controlling the learning experience toward predictable outcomes (e.g., Yerrick, 2000). Amir’s practice of open inquiry for these students struggling with school science stands in opposition to a view of teaching science associated with diluting content and the teacher presenting facts from the canon of science. Nevertheless, a few studies exist revealing that students struggling with science are engaged in inquiry, and, moreover, that inquiry is especially beneficial for these students (Lee, Buxton, Lewis, & LeRoy, 2006; Yerrick, 2000; Yerrick, Liuzzo, & Brutt-Griffler, 2012).

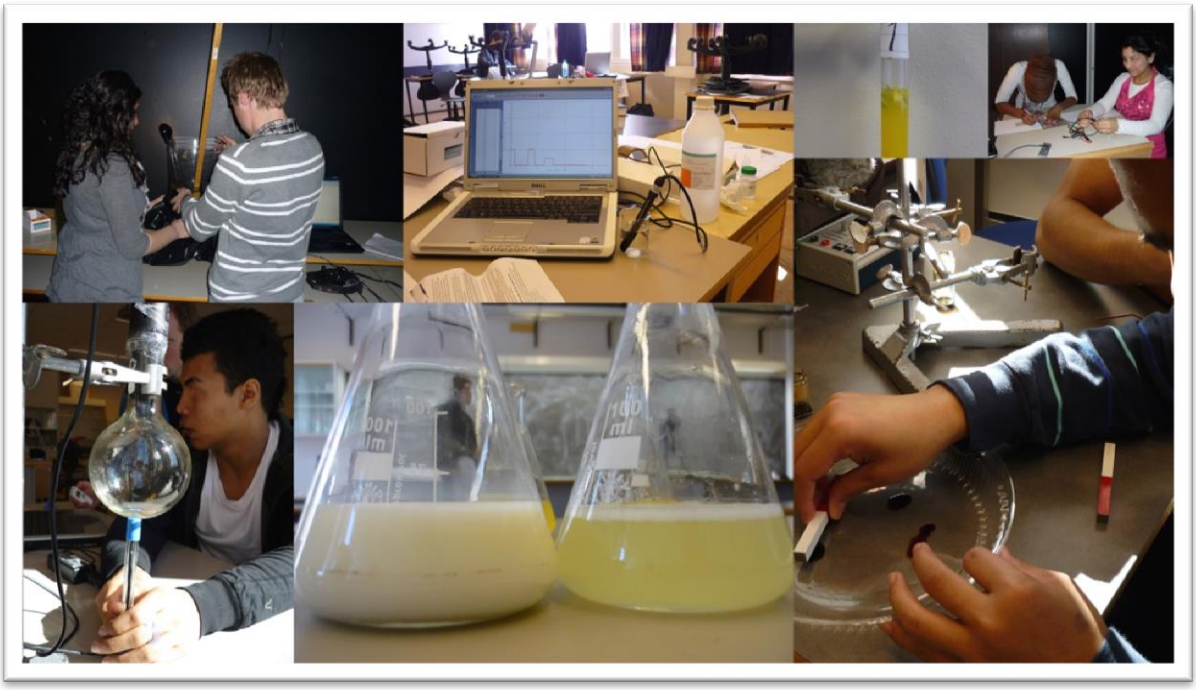
In contexts with low-achieving students, the implementation of open inquiry is uncommon and perhaps even controversial. The administration at Dale Upper Secondary School supported the open inquiry project, but in practice Amir felt that they were not helpful. The following objectives for the open inquiry project were formulated by the teachers and posted on the school’s homepage (the use of italics is preserved from the original posting):

- students should learn *the scientific method*
- arrange for the students to build their own knowledge by studying natural phenomenon, and stimulate their own curiosity
- increase the students’ ICT competences in natural science by use of digital sensors in field work, digital publications and an exhibition of their own results

- put a special focus on natural phenomena as a source of knowledge in natural science
- create interest in natural science by giving the students opportunities to play the role of *natural scientists*

The school had invested in modern school laboratory equipment. Compared with other upper secondary schools in Norway the lab was well equipped. Amir was the head of the science department, and his excitement for the students doing their own “research” had clearly paid off in the form of material resources. Especially impressive were the data loggers and the variety of sensors, making a diversity of data collection possible.

The project followed four phases: introduction to “the scientific method”; planning and design; performance and reflection; and presentation and publication (see Article II for details). The project period started in January, although the students had previously had training in some inquiry skills through small experiments, for example, how to observe different phenomena. The students worked in groups that they chose themselves and were given the opportunity to do research on a topic of their own interest. This was reflected through the great variety of research problems and designs. Some examples of students’ projects include: “The impact of solarium on the level of vitamin D in persons with different skin colour”; “Conservation of food using garlic”; and “Change of CO_2emissions in cars produced in the period from 1980 and 2007”. The students presented their projects at an exhibition at the school, using posters and material artifacts from the inquiries. An external group of teachers were judging their work and the three best projects won prizes. All the students and teachers at the school were invited to come, and both the local newspaper and television came and covered the event. The students were all excited during the exhibition; they were clearly proud of their work. The first and the second years of the action research project, there were five classes and approximately 100 students participating each year, however, the last year it was only Amir and his 26 science students.



Picture 1. Students working in the performing phase of the open inquiry project

Each year, the students were asked to evaluate the project and give advice to the next year's students. In general these evaluations were very positive; however, a few students also remarked that it was more challenging to be part of the open inquiry project than to participate in "normal" lessons. The following comments from the students were typical:

> I have enjoyed "the budding researcher" and I will absolutely recommend spending time on it. We have been allowed to work autonomously, but we have had teachers available when needed. The project has been a very good experience, and very fun to work on. A tip to next year's students: take time to find something you want to work on, it's often more difficult than it sounds :-D. (Sara, April 2008)

> I enjoyed this project. It was entertaining. A tip for next year's students: Do not leave work till later, do it when you have the possibility. (Erling, April 2008)

4.1.2 Teachers and researchers in the action research project

In this section I will provide some information about the participants in the project. The process of action research is discussed in Chapter 5.2. In the *first year* of collaboration (2007-08), the core group consisted of three well-qualified science teachers—Berit, Bernard and Amir—and two researchers—Erik and me. Erik was at the time an associate professor in science education and my supervisor, and I was a Ph.D. student with many years of experience as a science teacher. We were also colleagues in the teacher education department of the University of Life Sciences. I was new to action research at the time, while Erik had some experience from leading a teacher network. Berit and Amir were experienced teachers and both had master's degrees in science and some experience with research as well. Bernard held a Ph.D. in science, but he was quite inexperienced as a teacher. The *second year* of collaboration (2008–09), Berit did not continue to teach general studies science, and a new science teacher at school, John, took her place. He was an inexperienced teacher and wanted to be a part of the group to learn more about open inquiry. The *third year* (2009–10), Bernard got a position at another school and we got a new member in the group, Tomas. Both John and Tomas, being quite inexperienced teachers, wanted to implement more teacher-guided inquiry in their classes; hence in the final year only Amir implemented the open inquiry project in his science class. Erik was not participating on a regular basis this year; he attended meetings concerning the action research but did not do fieldwork. However, Amir and I decided to continue the process together to create continuity in the action research, and so that I could focus more deeply on Amir's scaffolding of the open inquiry project and how it constituted the students' inquiry process.

4.1.3 The teacher Amir

> It is strange if you have gardening knowledge and a large garden and only choose to look after the beautiful trees (...) and forget those that are malnourished or have injuries. (Amir, June 2010)

The quote is from a conversation with Amir in which he tells about his motivation for working at a school where most of the student are struggling with science and have little motivation for schoolwork. Amir is an experienced teacher with passion for his work, and he stays up to date on research in science. He is continually working to improve his practice, and he cares for his students as individuals. He has been working as a science teacher since 1998. At the beginning of his teaching career, he worked with a science teacher at another upper secondary school who had practiced teaching in the USA, and she introduced him to open inquiry. When he arrived at Dale Upper Secondary School in 2003, he continued to engage the students in open inquiry. It seemed like the school administration supported him on this, and he did not report any discontent parents or students. Amir was very enthusiastic about the project, believing that it was of special value for students with lack of interest in schoolwork. When "the budding researcher" was implemented in the natural science curricula, he was eager to share with the school, his fellow teachers, and us that the open inquiry project provided opportunities for the students to learn about scientific inquiry as described in the natural science curriculum.

4.1.4 *Amir's students the third year*

The final year of the project I placed a special focus on Amir and his scaffolding strategies, and how they constituted the students' inquiry process. Thus, I will give a picture of the students and the learning environment in Amir's science class from 2009–10. The class consisted of 26 students between 17 and 19 years old. The students were taking a third year of general studies, after two years in different vocational programs, to get a university and college admission certification. In a normal lesson, it was not unusual that one third of the students were absent, and that those coming to school often seemed a bit tired and uninspired. However, the group of students was not homogenous, and some students seemed to be more eager to learn and participate than others. Amir had a good relationship with the students. However, he also expressed frustrations concerning some of the students having strategies like "do as little as possible without failing".

I interviewed the students before they performed the open inquiry project. In the following quote, Cato, answers a question about what he would like school science to be like:

> Something you need and that is useful. Not only how an atom looks like in a beetle – what the hell are you going to use that for? However, in the last lesson we calculated the volume of lead, iron and things like that. That's useful knowledge. Then I think it (the science subject) is valuable and that you get something out of it. (Cato, 02.02.2010)

The utterance is representative of many of the students' answers; often they did not understand what science was useful for in their lives. However, there were also students telling that they enjoyed science at school:

> I like science very much. I've had a lot of lab work (Sofie, 02.02. 2010)

> This is the first year that I actually like science. Before we used to work only with exercises [in the textbook]. Now we are allowed to work in different ways.
> (Martha, 02.02.2010)

These utterances reveal that the students enjoyed practical work, and this was typical for the students in this class – and understandable given that they all had a background in vocational programs.

I decided to focus on one student group from this class in order to obtain rich data from Amir and his day-to-day interactions with the students during the open inquiry project. This student group consisted of three girls who knew each other beforehand, which was not the case for many of the students in this class. Two of the students, Marie and Martha, were not especially interested in science, but not reluctant either. The third girl, Sofie expressed more interest in science and motivation for the project than the two other girls. The reason for choosing these girls was not their level of achievement and interest in science; it was rather a pragmatic choice since they were not absent from school as often as some of the other students. I needed to follow the students from day to day. I have called this student group the "hair group" since their research examined how cigarette smoke influences hair quality. The "hair group" expressed after the project that they did enjoy the project. Martha stated the following concerning the open inquiry:

> It was fun working independently doing the inquiry about hair […]. I also enjoyed that the different groups in the class contributed with different research problems.
> (Martha, May 2010)

The quote is from a student evaluation of the open inquiry project in 2009–10. Martha's utterance was typical for the students, in that they enjoyed the freedom provided them by the teacher to inquire about something of their own interest, and moreover that they appreciated the opportunity to learn from the other students' projects.

5 Methodology

In this chapter I will consider methodological issues. First, I will give an account of the case study design. Then, the action research process will be presented, and I will discuss possibilities and constraints experienced in the situated practice. Furthermore, I will present the methods used for collecting and analysing data, and finally I will discuss the quality of the research and reflect upon ethical issues.

5.1 Case study

Miles and Huberman (1994, p. 25) define a case as “a phenomenon of some sort occurring in a bounded context”. The case study is used for its ability to examine, in-depth, a case within its real-life context (Yin, 2009). This comprehensive case study explores teachers and researchers developing open inquiry at Dale Upper Secondary School, based on collaborative action research. It includes two sub-cases, each representing single cases from Amir’s practice of open inquiry. The thesis also includes a reflective study based on two action research projects aiming to improve inquiry. The relationships between the studies are presented in Figure 1 (p. 6). I found the case study design to be useful following the guidelines in Yin (2009): The study wanted to answer “how” and “why” questions, and there were no clear boundaries between the teacher doing open inquiry and the context (the students, other teachers, the school administration, lab facilities, time limits, etc.). Moreover, these contextual conditions were important for the study. The cases in the present study can be characterised as “exploratory” since they were used to explore situations in which the interventions being evaluated had no single clear set of outcome (Yin, 2009).

5.1.1 Selection of cases

The comprehensive case was selected based on the opportunities to explore the implementation and development of the new natural science curriculum focusing on scientific inquiry and NOS, in a situated school practice. The reasons for choosing Dale Upper Secondary School are described in chapter 4.1. Action research was used as an approach to the development of practice because of the possibilities created through collaboration between teachers and researchers developing a practice together.

Single case studies provide in-depth and context-dependent understanding of the phenomenon (Flyvbjerg, 2011; Yin, 2009). The selection of cases is not random, but “information oriented selection, to maximise the utility from small samples and single cases” (Flyvbjerg, 2011, p. 307). Moreover, single case studies offer useful advantages in managing varied empirical material within the case and making them comparable (Yin, 2009). The two single cases in the present thesis are selected on the basis of expectations about the in-depth understanding of an experienced science teacher, Amir, developing and supporting open inquiry for students struggling with science. Amir was selected for the following reasons:

- He was an experienced science teacher, having performed open inquiry for several years.
- He was outspoken and willing to share his ideas, thoughts and reflections.
- He was willing to open up the classroom and share his practice of open inquiry.
- He created a safe environment for the students and prepared them for being a part of a research project.
- He was motivated to be part of a research project, and he wanted to spend time on it.

Amir was one of few upper secondary science teachers at the time who had several years of experience in performing open inquiry in Norwegian science classrooms. Moreover, in a school environment with students showing low achievement, teachers have a tendency to concentrate on factual science information (Johansen, 2013; Yerrick, 2000); however, Amir's strategy with these students moved in the opposite direction, bringing in student-active teaching methods and more complexity. Thus, the single-case studies exploring Amir and his practice provide possibilities for valuable and contextual information about the development of inquiry in a Norwegian school context.

In the *first single case*, the focus is Amir and his beliefs about NOS and scientific inquiry in the situated practice at Dale Upper Secondary School. The case lasted from 2007–2010, representing an in-depth and longitudinal study.

The *second single case* concerns Amir's scaffolding of his students, where I selected one group of students that I followed closely. The reason was that I wanted an in-depth and context-dependent understanding of the teacher's scaffolding and interactions with the students. In order to obtain that, I made appointments with these students and followed them wherever they went (mainly the classroom and school lab). Moreover, I was the sole field-researcher in the project in 2009–10, thus the choice of following only one student group seemed appropriate taking into account the time and resources available. The three girls in the "hair group" were chosen for the following reasons: They did not have too many absences from school, which was important since I wanted to follow them from day-to-day; they were willing to be a part of the research project and share their thoughts and opinions; and they agreed to be filmed and followed more closely than the other students in the class. The three girls in the "hair group" are also presented in Chapter 4.1.

5.1.2 Boundaries of the main case and two sub-cases

There is, according to Miles and Huberman (1994), a "heart" of every study with some boundaries that define the edge of the case. The comprehensive case study includes the teachers and researchers developing open inquiry at Dale Upper Secondary School, based on collaborative action research. The boundary was the school context, including school culture, teachers, students, school administration, and the researchers from the university. The data collection was in the form of observations from classroom practices and meetings between the participants, as well as interviews and informal conversations with students, teachers and school administration. Data from the entire action research project were reviewed holistically to provide rich descriptions of the school and classroom context, and to provide data for *Article III* focusing on developing practice of inquiry through action research.

The focus of the single case presented in *Article I* was Amir's beliefs concerning NOS and the open inquiry project. Thus, the boundary was Amir in the situated school context. The data collection was in the form of four in-depth interviews, and secondary data consisted of conversations and observations from the classroom and during the action research project from 2007–2010.

The heart of the single case in *Article II* was Amir and his scaffolding and interactions with his students during the open inquiry. The boundaries were Amir, his science class, the selected group of three students and material artifacts during the implementation of open inquiry. Data was collected through video recordings and site documents from the classroom in the period from January to April 2010, and secondary data was collected from interviews and informal conversations during the action research.

5.2 Action research to promote development of inquiry in school

In the following chapter I will provide reasons for choosing action research to develop and learn from a situated inquiry practice, and more specifically what it represents in this case study. Moreover, I will provide an account of the process of action research at Dale Upper Secondary School. Finally I will discuss possibilities and constraints of the action research.

In 2006 the Norwegian curriculum reform known as Knowledge Promotion was implemented as a reaction to the school reforms of the nineties, which embodied an educational system in which institutions, teachers and students were to a large degree under governmental control (Aasen et al., 2012). In a time when individual freedom and multiplicity were being demanded, there was a promoted change toward greater accountability of the school owner, schools and teachers. As part of the Knowledge Promotion, the subject curricula were developed to leave room for local curriculum development to take place. Moreover, the teaching profession should be strengthened through the anticipations of teachers developing local curricula and assessment in accordance with the national goals (ibid.).

Educational research shows that new understandings of inquiry develop, and new classroom practices emerge, in the context of teachers' collaboration with peers and experts (Anderson, 2002). The choice of an action research approach in the present case study provided the opportunity to help science teachers inquire into their own classroom practices, and take a critical perspective on theory and research in the field to improve their practice (Cochran-Smith & Lytle, 1999; Hodson & Bencze, 1998). Moreover, there is a need for more research that paints portraits of inquiry practices in a variety of settings (Crawford, 2014; Keys and Bryan, 2001) The local culture at Dale Upper Secondary School, representing mostly low-achieving students, is of interest as it plays a significant role in the teachers' interpretation of the inquiry practice. In the following section I will provide an account of the action research and discuss how the process had an impact on the choices made for the research focus in the project.

5.2.1 The action research at Dale Upper Secondary School

The point of departure was the collaboration between a group of science teachers at Dale Upper Secondary School and two researchers from The Norwegian University of Life Sciences. The collaboration was initiated by the researchers. Our common goal was to improve practice concerning the open inquiry project. The two researchers also formulated goals for the development of knowledge related to teaching and learning of open inquiry. Thus, the action research project had two main goals:

- To improve practice concerning the open inquiry project
- To develop knowledge connected to teaching and learning from open inquiry

There are many approaches that can be placed under the umbrella of "action research"; it covers approaches with different purposes, positioning, epistemology, ideological commitments and research traditions (Herr & Anderson, 2005). However, Carr and Kemmis (1986) provide a classic definition that is commonly used in educational action research:

> Action research is a form of self-reflective enquiry undertaken by participants in social situations in order to improve the rationality and justice of their own practices, their understanding of these practices, and the situations in which the practices are carried out (Carr and Kemmis, 1986, p. 162).

The approach provides a process for educators and others to individually and collectively study their own situations, try new practices, evaluate these innovations, adjust and try again. The process can be seen as a cycle of action and reflection, broken into phases of planning, acting, observing and reflecting (Elliott, 1991; Lewin, 1948). The action research at Dale Upper Secondary School is similar to more collaborative traditions of action research that have the goal of improving a practice and contributing to the knowledge base of the relevant field (Herr &

Anderson, 2005; Levin & Greenwood, 2001). The collaborative relationship between teachers and researchers is reciprocal, and the participants are supposed to contribute their different expertise and perspectives to the project (Herr & Anderson, 2005).

There was a division of labour in the action research project at Dale Upper Secondary School. The teachers and researchers collaborated to plan and reflect over their practice. However, the teachers had the main responsibility for the actions in the classroom, while the researchers had the main responsibility for facilitating the process of collaboration and collecting data for analysis. The process was characterised as research *with* teachers; however the research was not done *by* the teachers (Herr & Anderson, 2005).

The collaboration between teachers and researchers at Dale Upper Secondary lasted for almost three years, from August 2007 until June 2010. The following figure provides an overview of the organisation, the main participants and the processes of the action research during those three years.

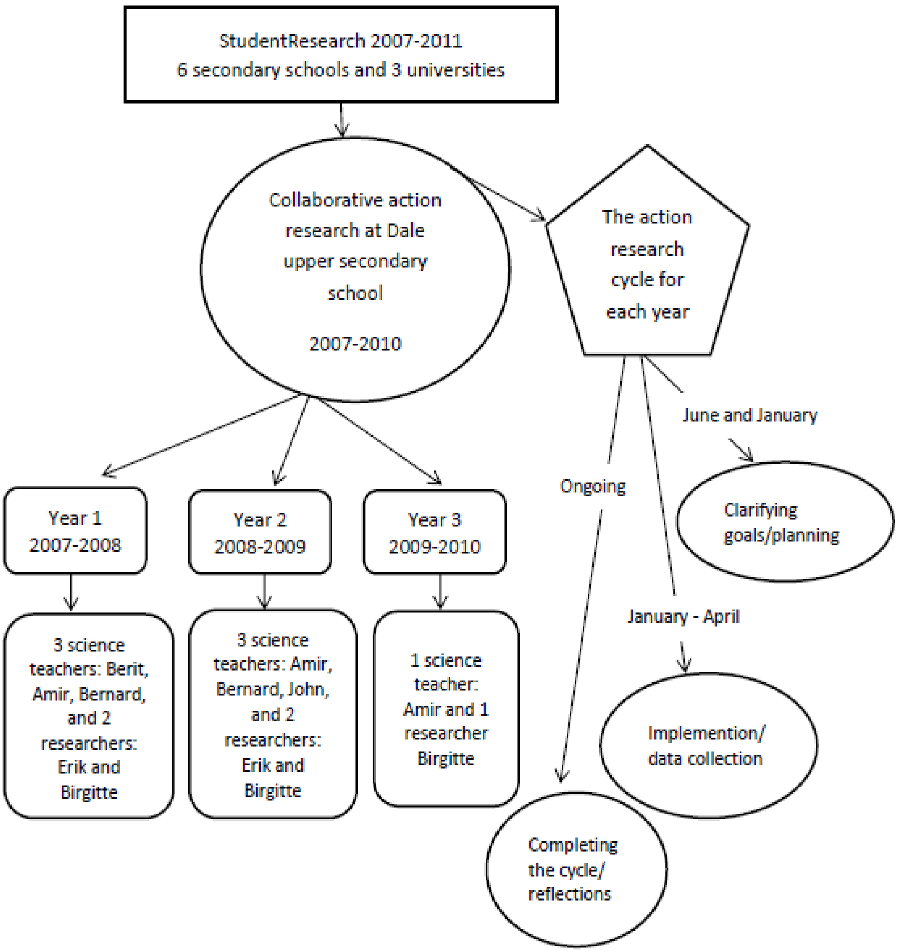


Figure 2. The organisation of the collaborative action research project over the three years

A description of the mother project, StudentResearch, can be found in Chapter 1.4. The context and the main participants of the action research at Dale Upper Secondary School are provided in Chapter 4. To sum up, two researchers and three general studies science teachers conducted the action research. In addition, one representative from the school administration and two or three science teachers working in vocational studies were present at meetings in the beginning and at the end of the project every year. The second year, a master's student in science education joined the group as well. The degree of involvement in the project varied amongst the participants, and two teachers and one representative from the school administration left the school and the project during the three years of collaboration. Thus, it was not a stable group and this did impact on the action research process; the choices made and the direction of the project.

5.2.2 The three cycles of action research

The *first cycle* of the action research provided, first and foremost, a possibility for the teachers to have their own experiences implementing open inquiry and for the researchers to observe the project. The following chart gives an overview of how we worked as a group to understand open inquiry, and make decisions for the way forward to improve practice.

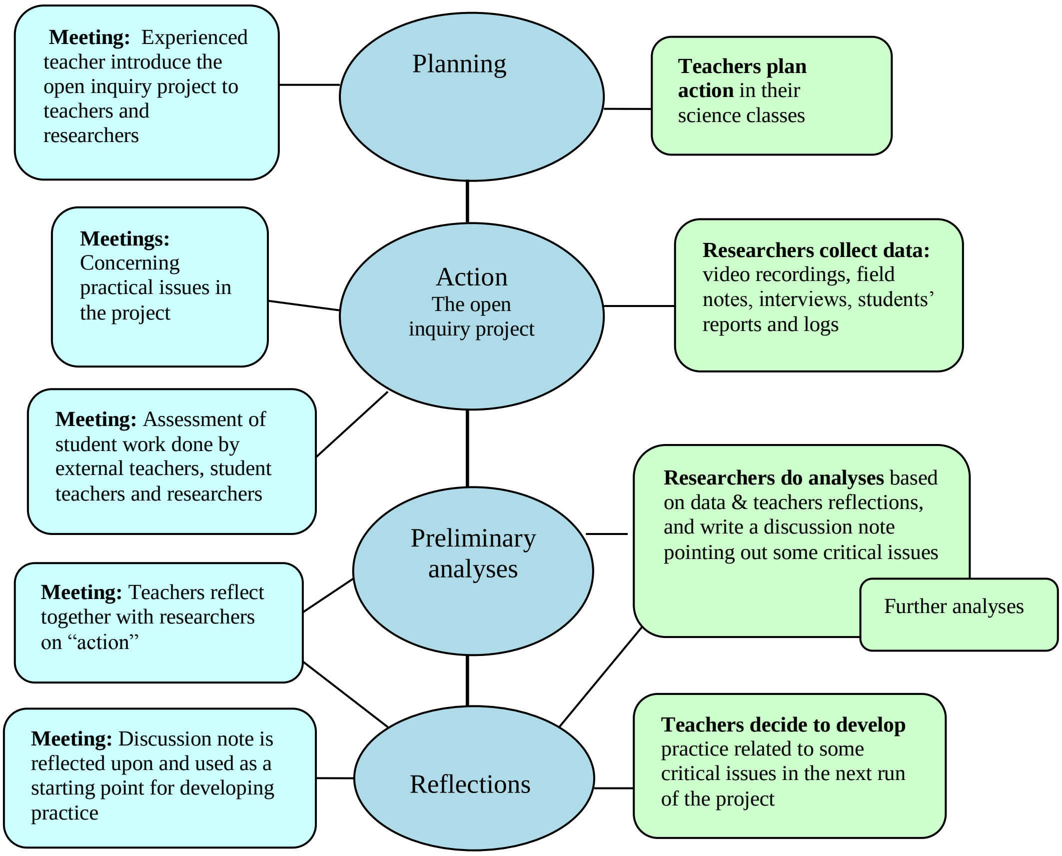


Figure 3: The first cycle of action research revealing how teachers and researchers collaborated

The first year of collaboration between teachers (Berit, Amir and Bernard) and researchers (Erik and Birgitte), started out following the traditional cycle of planning, acting, observing and reflecting, facilitated by the researchers. The researchers collected data in form of field notes, site documents and video recordings from two of the classrooms. We also audiotaped the meetings, and I performed in-depth interviews with the three science teachers (Amir, Berit, Bernard) and a short evaluation with the students. To follow up observations and reflections made in the first year of collaboration, we (the researchers) wrote a discussion note based on preliminary analysis of data collected during the first cycle. In the note we discussed some main problems with the open inquiry project, especially those put forward by the teachers, and we also suggested some possible changes of practice. The purpose of the discussion note was to use it as a point of departure for planning the following cycle of the action research.

The *second cycle* started up five months later in the following school year. We experienced how vulnerable an action research approach can be; one of the members in the group (Berit) was not teaching science that year, and the representative from the school administration had been replaced. Moreover, the school had problems with a large number of “drop outs” and a very high percentage of its students failing mathematics. Naturally, these problems had an impact on our teachers and the administration at the school concerning time and resources they could devote to the action research project. We were quite disappointed over this development, having spent much time and effort building up trust and reciprocity between the participants in the first cycle. In the second cycle the two science teachers familiar with the project decided to make some changes to their practice, including organising the students’ inquiry around a common theme, developing and using assessment criteria, and implementing “research meetings”. The newcomer to the project decided to become a participant in the project to learn from the group. However, the changes the teachers were trying to make were only partly realised in the second cycle; in the rough and tumble of the practice, the teachers fell back on the known way of doing things. The only significant change was the establishment of two “research meetings” during the process of open inquiry (Knain, Bjønness, & Kolstø, 2011). Moreover, assessment criteria were implemented, but not used actively in the students’ learning process.

Despite less development of the open inquiry project than the teachers had set out for, they reported mostly on beneficial experiences from the project during the second cycle. The following positive and negative experiences were listed by the science teachers and the school administration on the blackboard after cycle two.

Positive experiences: Variation from “normal” teaching; getting “new” students interested; going more deeply into the subject area; project lasting a long time; student cooperation (not more than 3–4 in a group); ownership of one’s own work; creating something;

understanding scientific inquiry; learning what it means to be a scientist; trial-and-error (it is ok to fail); students were good at finding theory, but they did not use it; contact with experts outside school; the poster exhibition; the student were proud of their products; promotion of the school – positive experiences are spread; interdisciplinary project.

Negative experiences: Takes too much time – wish for more efficiency through the project period; to little control – must have clearer structures and milestones; the students do not use assessment criteria – must be used more actively in the teaching process; more theory/use theory – method is not enough; ICT – need to install software in computers; time for meetings; control versus space is difficult; tidy up the lab.

Thus, the teachers seemed to be quite satisfied with the open inquiry, and they had some ideas for improvement for the third cycle. Moreover, the school administration said the project was good publicity: Over 100 students in five classes presented their projects for the whole school, and the local television and newspaper reported on the project.

In the *third cycle* at Dale Upper Secondary, yet another teacher (Bernard) in the action research group quit the school and the project, and once more we got a new science teacher in the group. However, the two teachers relatively new to the project found the open inquiry project too demanding and wanted to implement more structured inquiries in their classes. In order for me to get some continuity in my research project, I decided to follow and collaborate solely with Amir in the last cycle. This also provided a valuable opportunity to focus on Amir's scaffolding of the open inquiry project and how it constituted the students' learning process.

Thus, in the course of action we learned that it is difficult to facilitate action research, being novices to the approach. The frames and tools for supporting the action research at the school were not ideal – and perhaps they never are. Moreover, Amir had a more prominent role in the project than the other teachers. He was the one who developed the open inquiry project in the beginning, and he was also the initial contact between the university and the school. During the process of collaboration, we experienced that the unequal "power relation" between the teachers became problematic in the sense that Amir had a dominant position in the teacher group, which might have influenced the process: it became easier for the other teachers to retreat from the project when they were striving with the implementation, and sometimes Amir seemed to pacify some of the others teachers—having "all the answers". The process of the action research was complex. The collaboration between participants was marked by barriers both inside the group (e.g., teachers quitting, limited time) and outside (e.g., the school administration did not allocate enough time for meetings). Moreover, the planned change from one cycle to the next was not necessarily followed up by the teachers in practice.

In a sister project within StudentResearch many similar challenges were experienced by a fellow Ph.D. student, Gerd Johansen. In both of the practices, teachers and researchers decided to implement changes, but little happened. Gerd and I started to discuss what kind of resources and methods of collaborations could enable a change in practice. Our concern was especially the *transition* between planning change and what happened in the actual classroom practice. Moreover, we were concerned about our role as researchers in the collaboration, and how to bring in relevant perspectives from educational research. We read a lot of action research literature, but nevertheless we did not really find solutions to our problems. These challenges became the point of departure for Article III about how to mediate change in science inquiry through collaborative action research.

5.3 Challenges and possibilities with action research in school

Action research is proposed as a suitable approach for curriculum development, teacher professional development and research in a situated school context. The present action research did not result in a "happy ending" to document. The teachers wanted to make changes in their science inquiry practice, but little happened because of conflicts between their goals for learning and their actions as teachers. The study illustrates how difficult it can be for teachers to make the wanted changes to their inquiry practice. Herr and Anderson (2005), underscore that action research does not automatically lead to "successful" change, and they suggest that "failed" attempts are important to document in terms of increasing our understanding of the complexity of the change process. Thus, in the following I will provide a list of some of the challenges—and possibilities—we experienced in the collaborative action research at Dale Upper Secondary School. These should not be regarded as normative standards; rather they present some areas of experienced practice that can be valuable in understanding the complexity of a change process. Reference to research literature is provided for central concepts where it is relevant.

Experienced challenges and possibilities concerning collaborative action research:

- Action research is time consuming. The process of action research must be explicit and negotiated with the school administration to secure support in form of time and resources for developing practice.
- The benefit from the collaboration is very dependent on the *relations* between participants (McArdle, 2008). Unequal "power relations" can lead lack of participation and development.
- *Reciprocal trust* (Grant, Nelson, & Mitchell, 2008) between the participants is important to develop a common language and understanding of the phenomenon (e.g., open inquiry). The teachers need to trust that the researchers understand the possibilities and challenges in the situated practice.
- The "*double burden*" of improving practice and doing formal research (Herr & Anderson, 2005) turned out to be more complex and demanding than expected from reading literature.

- The close collaboration over a prolonged period in a situated practice, can lead to the danger of the researcher developing the same "*blind spots*" as the teachers. Thus, the researcher needs an intellectual distance to the practical context so that the critical and analytical focus does not dissolve (Hammersley and Atkinson, 2007)
- The "*dynamic conservatism*" in schools (Schön, 1983), for example the teachers' norms, rules, skills and values, is a strong force that can prevent change and improvement. In order not to reproduce current practice there is a need to focus on the *negotiation* of what the teachers want out of the action research project (Engeström, 2001).

Moreover, in an extensive after-field interview with the participants in the action research projects at Dale and Hill upper secondary schools, the teachers and researchers respectively listed what they/we saw as the main possibilities regarding collaborative action research, answering the following questions:

What can teachers get out of collaborating with researchers?

- To "play ball" with the researcher(s) and get perspectives on own practice from the outside.
- Thinking together about a common project or teaching unit makes the reflections more systematic and explicit.
- The researcher can contribute in the creative process of developing practice.

What can the researchers get out of collaborating with teachers in prolonged fieldwork?

- Observation over long time is valuable to get to know the context in order not to judge the situation after normative standards.
- Observation over time provides a rich and in-depth understanding of the phenomenon—the criteria for success might be hidden in the situated practice.
- The understanding that there exist no "quick-fix" when it comes to improving practice in school.
- A practice-based understanding of how to perform research and development of a classroom practice in close collaboration with teachers.

In Article III, we further elaborate on and discuss the possibilities and constraints of collaborative action research. We experienced two main challenges that were not greatly problematised in the literature: the *transition* from planning changes to actions in the classroom, and *how* to incorporate relevant perspectives from educational research. In Article III, we discuss these two issues and argue that the concepts of *tools* and *multi-voice* provide valuable perspectives that can complement action research strategies.

5.4 Methods for collecting data

An effective data collection design for qualitative educational research includes as many different sources as possible, according to Erickson (2012). Moreover, action research can be fruitfully combined with multiple methods for data collection (Herr and Anderson, 2005). The process of action research and collection of data for the three articles with their different perspectives included the following methods:

- Video-recordings and field notes from teaching sequences
- Site documents: template for the project on the students' learning platform, assessment criteria, log and reflection notes, students' posters and reports from the inquiry project
- Semi-structured interviews with teachers and students
- Focus group conversations with teachers, researchers and school administration

In the following section, I will provide an account of methods that were used to collect data. Data was collected from practices observed within the classrooms, as well as meetings and interviews outside the classrooms. The amount of data collected during the three years in the field was extensive, and only a part of it was used for the analysis that appeared in the three articles.

5.4.1 Participant observation in the classroom

Participant observation has the following attributes: The researcher establishes a direct relationship with the social actors, staying in their natural environment, with the purpose of observing and describing their behaviour by interacting with them and participating in their everyday ceremonials and rituals, learning their code (or at least parts of it) in order to understand the meaning of their actions (Gobo, 2008, p. 5).

Amir was the sole teacher who we followed on a daily basis in the classroom. In order to understand Amir and his implementation of open inquiry in a situated practice, interviews and conversations with the teacher were not sufficient, since there will always be a gap between attitudes and behaviour, what people say and what they do (Gobo, 2008). Thus, to follow the everyday life of Amir's science classes for four months each year became important for the study as a whole. In order to collect data from the classroom practice, we made use of several methods, including direct observations, field notes and video recordings.

In the first cycle of the action research, Erik and I observed Amir's practice together, while I did the main observation in the next two cycles of the project. There was a division of labour wherein Amir was teaching the students, while we were observing and collecting data in the classroom. In the second cycle I had a more prominent role implementing "research meetings" in the classroom practices of Amir and Bernard, and a master's student provided an introduction lesson with the students on "measuring uncertainty" that was relevant to the inquiry project.

One of the problematic aspects of performing participant observation is the double role the researchers must take on, participating in the social life of the actors being observed, while at the same time maintaining sufficient distance to perform the research satisfactorily (Gobo, 2008). This was something that we as researchers constantly reflected on. The fact that there were two of us following the practice helped us maintain a necessary cognitive distance. This was important in order to avoid getting the same "blind spots" as the teachers—allowing us, for example, to ask critical questions regarding the teachers' lack of support concerning *how* to use theory to inform the students' inquiries. Moreover, Gobo underlines that, from a practical point of view, constantly reflecting, taking notes, asking questions, recording, taking photos and interpreting prevents the researchers from getting completely "inside" the culture in which they study. Thus, Gobo suggest that being simultaneously "inside" and "outside" the cultural code is a normal component of the researcher's role during participant observation.

In the present study we were participant observers using two primary means of data collection: looking and asking. Erickson (2012) proposes that the ideal research process is "a recursive process of observation and interview in which, at each step along the way, insights gained by one method (either by looking or by asking) are followed up using the other method." (2012, p. 1455). The present research followed such a recursive process in which observations were followed up by interviews and informal conversations, and new observations were influenced by the conversations. This recursive process was enabled by the prolonged time we spent in the field, and it provided an opportunity to understand open inquiry in depth. The next sections will provide accounts of how we performed this "looking and asking".

5.4.2 Video recordings from the classroom

In qualitative educational research, video recording has been described as a fruitful strategy for collecting rich data from detailed day-to-day events in the "real world" of the classroom (Derry et al., 2010; Jordan & Henderson, 1995). The video recording has different purpose for the three studies included in this thesis.

In Article II on the teacher's scaffolding of the students' learning processes, the video recording provided data from the teacher-student and student-student interactions during the entire open inquiry, with a focus on the teacher and the "hair group". The video recording worked as the foreground of the data analysis, while other data such as interviews worked as background data, informing the analysis of data from the video recording. The video recording enabled me to study the speech and actions of the participants in the classroom (Jordan & Henderson, 1995). I had to operate the camera myself, so I used the same camera for whole-class interactions and for filming the "hair group". This did not create significant problems since I only video-recorded one student group. The camera had a wireless microphone that was placed on the students' desk to obtain optimal sound. The video-film covered the three students and their "working space", including their PC's and material artifacts they used and produced during their inquiry. I did not stand behind the camera during the recording so that I did not interfere in the students' speech and performance. The students habituated quickly to the camera—they soon started chatting about everyday things and stopped noticing that they were being filmed.

In Articles I and III, the video recording from Amir's science classrooms over three years worked as secondary data, being part of the recursive analytical process in which observations from the classroom were followed up by interviews with Amir and his students. Video recording also represented background data that was reviewed holistically to provide rich descriptions of the classroom context (Derry et al., 2010).

Field notes were used to make notes about each lesson concerning date, time of the day, the main purpose of the lesson, and the students' whereabouts. I also wrote down general descriptions about the classroom environment (students being tired or excited, etc.) and incidents that were of special interest to help my memory. Since I was video recording all of the lessons for close analysis, I was not very concerned about the accuracy of the field notes, but I tried to keep the notes as concrete and close to the practice as possible.

5.4.3 Semi-structured interviews

The interviews in the present case were semi-structured. In general, the goal of semi-structured interviews is, according to Kvale (2006), to obtain descriptions of the interviewees' worldview, with the purpose of interpreting the described phenomena. In total, I performed four semi-structured interviews with Amir before (appendix 1), during (appendix 2) and after (appendices 3 and 4) the action research project. In addition, all the science teachers were interviewed after the first year of collaboration (appendix 2). The questions were organised around central themes connected to the performance of the open inquiry, the participation in the action research project, and the teachers' views about NOS. The atmosphere was relaxed during the interviews; the teachers knew me well after having spent a lot of time at the school. They also knew that I had been working as a science teacher myself, and this was probably important so that they knew that I understood their work from the "inside".

These interviews constitute the primary data for Article I concerning Amir's beliefs about NOS and the situated practice of open inquiry. There are standardised tests for analysing teachers' and students' views of NOS (e.g., Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). However, I believe that the semi-structured interview worked well as a means to let Amir speak more freely about the complex subjects of NOS and scientific inquiry, and relate them to his own practice in the classroom. Moreover, interviews and conversations over the course of three years made it possible to assess whether a statement was typical or discrepant from other utterances. Video recording from the classroom worked as background data and made it possible to ask Amir to explain elements of the classroom practice or confront him with the parts of the practice that were different from what he actually said he was doing.

Moreover, I performed a semi-structured interview with the "hair group", appearing in Article II, after they had finished the open inquiry project (appendix 5). This had a double purpose: It provided the students with the opportunity to debrief after being followed closely and videotaped, and it also contributed contextual understanding about the students' learning process. The students were relaxed in the interview setting since they knew me well, and they were eager to share their experiences.

Furthermore, Article III builds partly on reflection and evaluation from a semi-structured group interview (appendix 4) for four hours with Amir and Birgitte from the present fieldwork, and Ellen (teacher) and Gerd (researcher) from a sister project within StudentResearch. We met at the University of Life Sciences after the prolonged fieldwork (for three and two years, respectively) to reflect on the possibilities and constraints of collaborative action research. We also hoped to work together to develop a sense of the ideal meeting point between schools, teachers and researchers in developing classroom practices.

5.4.4 Overview over the data material

Table 2. Description of data corpus on the case study at Dale Upper Secondary School

Type of data	Description of data
Video recordings from the classroom cycle III 2009–10	28 hours of video recordings. The video recordings capture both whole-class introductions by the teacher, and the "hair group" during their inquiry. This data was used for analysis of Amir's scaffolding of the open inquiry. Data functions as primary data for Article II and secondary data for Article I and III.
Field notes from the classrooms cycle III 2009–10	Notes taken about the educational setting (time, place, students) and particular events that occurred during the lessons. The field notes worked as background data.
Site documents from the classroom cycle III 2009–10	PowerPoint of Amir's presentation of the open inquiry project. Template at the learning platform for the project, including students log and teacher's feedback to the hair group, and assessment criteria. Report and poster from the hair group's project. This source provides data for analysis of Amir's scaffolding of the open inquiry. Data functions as primary data for Article II.
Interviews Amir 2007–10 (audio)	Four semi-structured interviews with Amir, in total 8 hours. This type of data provides information about the teacher's beliefs concerning NOS and teaching open inquiry. Data from interviews functions as primary data for Article I and III, and secondary data for Article II.
Interviews students 2009–10 (audio)	One-hour group interview with the hair group, providing additional data about the students' participation in the open inquiry project.
Meetings, interviews, site documents and classroom observations for the action research project 2007–10	Several-hour audio recording of meetings in the action research group. Audio recording of semi-structured interviews with teachers and students, and moreover video recording from the classroom practices over the three cycles. This information was part of the process in developing the open inquiry project at Dale Upper Secondary School. It also provided secondary data for Article I, II and III, and rich descriptions of the context.

A corpus of data can function as primary data for analysis in one article, and be regarded as secondary data in another article. This is natural, taking into account that the data is being drawn from the same practice of open inquiry, but with different perspectives and levels of framing.

5.5 Data analysis

The three studies in the thesis have different analytical approaches even though they all originated from the practice of Amir and the action research project. The choice of data analysis has been made according to the focus of the individual studies.

Article III is built on two separate action research projects as well as semi-structured interviews with the participants. The article is both theoretical and reflective, but it does not present findings in the traditional sense but rather reflections and insights exemplified and illustrated using empirical data from the two projects.

Articles I and II report from two single-case studies. In both cases we used an interpretive design suggested by Erickson (1986, 2012). I do not intend to describe the analytical approaches in detail, as they are thoroughly described in each of the articles. However, I will provide an account of some of the analytical procedurals such as transcriptions and coding of interviews and the video recordings from the classroom. Moreover I will provide reasons for choosing narratives to convey Amir's beliefs (Article I), and why interaction analysis was used to analyse Amir's scaffolding of his students (Article II).

Article I concerns Amir's broader ecology of beliefs about NOS and the practice of open inquiry. The primary data include four in-depth semi-structured interviews with Amir, eight hours in total, during three years. The interviews were all transcribed, representing the discussion between Amir and me in three of the interviews, and Gerd, Ellen, Amir and me in the fourth interview. I performed an open coding of the transcripts, searching for patterns and discrepancies to confirm or disconfirm some working assertions, and clustering of codes for the modified assertions. Then I made mind-maps as a visual thinking tool to structure and explore the relationships between concepts related to each of the assertions (one example is provided in appendix 6). We (Erik and I) found three emerging dimensions of the teacher's beliefs concerning NOS and the situated practice of open inquiry, represented in the article in form of narratives. One methodological issue is whether interview responses are to be treated as giving direct access to 'experience' or as actively constructed narratives involving activities which themselves demand analysis (Silverman, 2000). I follow Silverman in that I do not think that people attach a single meaning to their experiences; it is dependent on the situated context. In this case, we were interested in the teacher's beliefs, and the interview data can be seen as accessing stories or narratives through which Amir reveals his worldview. Thus, we did not treat Amir's accounts as "true" pictures of "reality". Rather, in concert with him, we generated accounts of his beliefs in the form of narratives. I wrote the narratives from the analysis of the interviews, while the quality control consisted of, first, Erik reading and commenting on the narratives, and then Amir himself reading and commenting as well. To emphasise the patterns in Amir's beliefs, we also complemented the narratives by using excerpts from interviews, as well as discrepant statements concerning his beliefs. To sum up, we made a cognitive map (Miles & Huberman, 1994) to make visible the connections between his beliefs.

Article II concerns Amir's scaffolding of his students during the open inquiry. The primary data source was site documents and 28 hours of video recording of the "hair group" and entire class sessions during the project lasting four months. The video recording was used for interaction analysis inspired by Jordan and Henderson (1995). My interest was the teacher's scaffolding of the students' inquiry process from the beginning to the end, observing the naturally occurring interactions between the participants in time and space. This part of the analysis was also inspired by Högström and co-authors (2010) performing interaction analysis on practical work. The interaction analysis started by looking through the material to identify how teacher-student and student-student interactions were structured, and what made the participants act the way they did. The identifications were also inspired by relevant literature, in addition to in-situ observations and interviews. Performing an analysis at an intermediate level, trying to cover the teacher's scaffolding in all the phases of the project, was time-consuming and demanding. However, the iterative process of discussing preliminary findings with researchers in StudentResearch, reviewing the video recordings and reading literature concerning teachers' scaffolding of open inquiry, was helpful in identifying *issues* appearing to be of importance. The *emerging issues* were connected to the teacher's scaffolding and how it provided the students with both *structure* and *space*—for example, how the teacher directed the students' ideas in a certain direction by asking questions (structure), or how he motivated them to follow their own ideas (space), and the consequences of these strategies for the participants' interactions (short versus long discussions, words and concepts that were continuously repeated, expressed frustrations or excitement – see Article II). Issues emerging across instances were identified as robust (Jordan & Henderson, 1995). Moreover, these emerging issues were transcribed, representing the participants' talk, object manipulation, document processing and employment of PC and data-loggers, and aspects of the students' body language, such as excitement or boredom.

5.6 The quality of the study

5.6.1 Reliability

In qualitative research, reliability refers to "whether the process of the study is consistent, reasonably stable over time and across researchers and methods" (Miles & Huberman, 1994, p. 278). However, it is important to bear in mind that human behaviour is never static, and opinions and attitudes may change over time, so no study can be replicated exactly, regardless of the methods and design employed (Gobo, 2008).

In order to consider the reliability of the research participants, Gobo (2008) writes that it is important to collect rich data during prolonged fieldwork. In the present action research, I was in the field for three years, following every science lessons for four months each year. It involved numerous observations so that information could be adjusted or corrected by subsequent observations (Gobo, 2008). Baxter and Jack (2008) also underline the advantage of prolonged fieldwork to establish a rapport with participants and to collect multiple perspectives in order to understand and reduce the potential for social desirability responses from the participants (Krefting, 1991). The prolonged period I spent at the school minimised the tendency for the teachers and the students to exhibit behaviours for the benefit of the researcher. Finally, the prolonged fieldwork familiarised the participants with each other, thus reducing intrusiveness (Gobo, 2008).

However, one of the problematic aspects of spending a long time as a researcher in a school context is the danger of developing the same “blind spots” as the teachers. This was perhaps especially challenging for me since I was a science teacher for eight years, and at the time I was a novice to educational research. The collaboration with my fellow researcher, Erik, for the two first years of the project was therefore especially valuable in helping me avoid going “native”. Moreover, the collaboration provided an important arena for discussing the observed practice. We were able to scrutinise situations together, bringing in different perspectives, since Erik was an experienced researcher and I had extensive experience as a science teacher at an upper secondary school. Moreover, Erik has been reviewing data and provided valuable input into the articles.

Transparency in regard to the researcher and the research process is important for the study’s reliability (Gobo, 2008; Thomas, 2010). In the present study I have tried to be transparent about my role as a researcher in the action research project, as well as about my preconceptions of the phenomena. The action research process, its participants and the context at Dale Upper Secondary School are presented thoroughly in chapter 4 and 5. However, it is difficult to be transparent about all the processes going on in a prolonged action research project. Nevertheless, I have tried to be clear about the main difficulties and possibilities, and how they have influenced the choices made along the messy road of research. These choices were, to some extent, pragmatic solutions, taking account of the teachers’ limited time, as well as my own limited time as a Ph.D.-student who worked part-time in science teacher education.

Furthermore, video recording provides some advantages concerning transparency since they are available for other researchers (Silverman, 2000). In the present study, the collaboration with other researchers in StudentResearch contributed to openness since data were shared and discussed during the iterative process of data analysis. Moreover, the use of the computer-assisted qualitative data analysis software ATLAS for analysis of text and video material, made the analytical process more transparent, since it could be made available to other researchers as well.

5.6.2 Validity

According to Miles and Huberman (1994), validity in qualitative research concerns the "truth value" of the research, answering questions like "Do the findings of the study make sense? Are they credible to people we study and to our readers? Do we have an authentic portrait of what we are looking at?" (p. 278). Validity can be regarded as a process of checking, questioning and theorising in which the material and its interpretations are scrutinised for bias and checked to see whether they are plausible and manageable (Kvale, 2006).

Triangulation of data sources, data types, or researchers is a primary strategy that can support the principle that phenomena should be viewed and explored from multiple perspectives (Miles & Huberman, 1994; Yin, 2009). In the present study, this triangulation was done through data sources (teachers, school administration, cycles of open inquiry with different student groups), data collection methods and types (participant observation, interview, video, site documents) and researchers (co-authors). These triangulations enhanced data quality based on the principles of idea convergence and the confirmation of findings (Baxter & Jack, 2008; Gobo, 2008). Moreover, the collaborations with co-authors familiar with the setting of Dale Upper Secondary School provided valuable discussions during which the interpretation of the phenomena were explored and clarified (Baxter & Jack, 2008).

There has also been a process wherein our (the researchers') interpretations of the data were shared with the group of teachers in the process of action research; one example of this is the "discussion note" from the first cycle. Another example is provided in Article I, in which Amir's beliefs concerning NOS and his practice of open inquiry were conveyed in form of narratives. He was provided with our interpretation of his beliefs, and he supported the representation and made some elaborations and clarifications that were taken into account. Moreover, in Article II Amir and his scaffolding of open inquiry were the focus of the case. The interpretation of Amir's scaffolding of the students has not been shown to Amir or the three students. The analysis and interpretation is based on data from the classroom and does not rely on the participants' opinions or attitudes. Nevertheless, I had interviews and conversations about the teacher's scaffolding that function as secondary data in the article. The interpretation was given particular support by Erik and Stein Dankert, both of whom are familiar with the project and the setting.

I have tried to be transparent concerning the context and the choices made during the research process. However, I find that the article format for publication, which is restricted to

8,000–10,000 words is limiting for qualitative studies depending largely on presenting context-rich and meaningful descriptions, as are the present articles.

5.6.3 Generalisability

Generalisability is one of the most controversial issues within qualitative research (Gobo, 2008; Silverman, 2000). The word is drawn from quantitative studies, but it means something different in qualitative studies, such as case studies. It is claimed that single cases offer a poor basis for generalisations. Such critics are, according to Yin (2009), implicitly contrasting the case study to survey research relying on statistical generalisations. However, case studies rely on *analytical generalisations,* where the researcher is striving to generalise a particular set of results to some broader theory (Silverman, 2000; Yin, 2009). This form of generalisation involves a reasoned judgment of to what extent the findings in one case can be used as a guide for what may happen in other situations (Kvale, 2006). Analytical generalisation is dependent on rich contextual descriptions of the case. Moreover, the researcher must argue for the transferability to other situations so that the potential reader can judge the soundness of the generalisations (Kvale, 2006; Miles & Huberman, 1994). Analytical generalisations are dependent on findings based on the combination of theoretical assumptions guiding the study, findings from the empirical analysis and related research (Miles & Huberman, 1994; Silverman, 2000).

The present case study was chosen on the basis of the expectation of in-depth and contextual understanding of open inquiry in a situated practice. This type of selection maximises the utility of information from small samples and single cases (Flyvbjerg, 2011). The implementation of the new natural science curriculum in Norway focusing on scientific inquiry led to a need for a better understanding of how it could be realised in the classroom, and of the curriculum’s possibilities and constraints. Thus, I choice to follow Amir because he had several years of experience with open inquiry, and the practice is of interest since it is close to the new (at the time) main area named “the budding researcher”, but yet not a common practice in Norwegian classrooms. Moreover, from international research about open inquiry, I found that there were (and still are) discussions concerning its value in helping students learn about scientific inquiry. In this extended essay and the individual articles, I have documented studies on science inquiry, in particular the teacher implementing open inquiry, in diverse educational settings. Theoretical assumptions were made for the study, and the findings generated from empirical analysis of the single case studies were discussed in relation to key studies in the field.

Flyvbjerg suggests that “[…] formal generalisation is overvalued as a source of scientific development, whereas ‘the force of example’ and transferability are underestimated.” (2011, p. 305). I believe that the processes and outcome described in the present thesis are applicable in other settings (Miles & Huberman, 1994). Moreover, I hope the implications of the study are valuable in providing real-world cases and “thinking tools” for science teacher education and teacher professional knowledge.

5.6.4 Ethical considerations

The action research approach entails close collaboration between people. During the process, we became close to the teachers, students and the inner life of Dale Upper Secondary School. This led to several ethical considerations to be made – before, during and after the fieldwork process (Postholm & Moen, 2009).

Before the fieldwork. The “StudentResearch” project was approved by the Norwegian Social Science Data Services (NSD), which manages the approval of research, ethics, data handling and data storage. The action research project at Dale was approved as part of “StudentResearch”. Moreover, guidelines from NSD were used when the participants—including the school administration, the teachers and the students over the course of three years—gave their informed consent. According to Gobo (2008), participants must be fully informed about the goals of the research so they can decide whether or not to give consent. However, in an action research project, there are no clear, predefined goals. We began with an aim of developing a practice of open inquiry, and later in the process, goals were formulated as part of the collaboration between teachers and researchers. Since this was a collaborative effort, I do not find it ethically problematic that there was no predefined goal. Moreover, clear information about the aims of the two case studies was provided from the beginning, both in relation to Amir and to the student group. Likewise, the teachers were well informed about the purpose of the action research study.

The underlying premise when choosing an action research approach for development and research in schools is that the teachers are interested and willing to participate (Tiller, 2006). Due to continuous demands placed upon schools and teachers in today’s knowledge society, teachers are expected to learn continuously (Beijaard, Korthagen, & Verloop, 2007). The teachers at Dale Upper Secondary were interested in participating in the project; they saw it as a possibility for professional development in science inquiry. However, the time for reflections together as a group was limited, and in retrospect I think we, the researchers, should have taken greater responsibility for negotiating time and resources with the school administration before entering the field.

During the fieldwork. Gobo (2008) proposes that researchers’ power and authority should be scaled down and contextualised during fieldwork. As newcomers to the field and to action research, we (the researchers) were probably more cautious not to step on any toes than was strictly necessary. It was important for the collaboration between teachers and researchers to establish a safe environment where all the participants could speak freely, and as researchers we were eager to understand the teachers’ point of views. In retrospect, I believe that we should have brought in more new perspectives into the conversations with the teachers, and asked more critical questions about the practice of open inquiry. According to Postholm and Moen (2009), the researcher must also ask questions to provide room for new understanding and perspectives. Some of the experiences concerning multi-voice as a means for change in action research are discussed in Article III. Gjøtterud (2009) proposes that the researcher/facilitator in action research must be sensitive and find a balance between "love and critique". To find this balance is probably highly dependent on the researcher's experience on how to facilitate the action research process, and the ability to understand the relationships within the group of participants, in order to be able to act upon obstacles and possibilities.

The teachers chose themselves if they wanted us to follow their teaching in their classrooms. For the two first cycles, we followed Amir and Bernard and their students. There were some students in Bernard's group who did not give consent for video recording; however, all the students in Amir's class for the three cycles of the project provided consent. This showed us how important it was that the teacher explained about the purpose and nature of the action research project together with the researcher. Amir's ability to make his students feel safe concerning our presence was crucial for being able to video-record the whole class. Spending time in the class together with the students before starting the video recording was important as well, especially concerning the "hair group". I did ask them during the project how they felt about the camera and the research project, and they did not make any negative comments. Moreover, I performed interviews with respectively the teacher and the "hair group" after the project, where I opened up for debriefing about how they felt about the process and being part in a research project. Amir told me that he felt the project was important, and that he found it exciting to discuss science education together with us in his situated context. The students found that being part of a research project was fine and they were curious about the result, however they also expressed that the interviews with me took a bit long time.

After the fieldwork. The school's name and the names of people occurring in the thesis are pseudonyms, except the researchers' names. The school is situated in the most densely populated area in Norway, and there are or more than 60 upper secondary schools in the area. Thus, the school and the participants' anonymity are hopefully ensured.

Some ethical considerations have been important concerning the publication of articles, especially concerning Amir and his practice. A comprehensive ecological view of ethics suggested by Flinders (1992) includes the researcher being sensitive to the language and meanings of the local "culture" and to consider during writing articles "how to act responsibly in making public what we have learned". We (Erik and I) had mutual respect with Amir, and it was important for us to convey his beliefs and practice in a manner that he would recognise. In Article I, we use narratives to represent his beliefs concerning NOS and his practice of open inquiry, and we had many conversations about the ethical issues regarding of presenting Amir's beliefs. Did we make it clear for him during the fieldwork the level of analysis? Was he going to feel uneasy with our interpretations? Taking into account his well-founded and reflective elaborations concerning NOS and why he performed his practice as he did, we found that his perspectives provided a rich understanding. Thus, as part of the process of analysis, we sent him the narratives and he endorsed them and commented on a few of them, increasing the validity of the study as well as improving ethical concerns. The article about Amir's scaffolding of the "hair group" has not been reviewed by him or the students. However, the recursive process during three years in practice focusing on Amir and his practice in addition to video recording of the interactions in the classroom ensured reasonable representation of Amir's and his students. In addition, I performed interviews after the fieldwork with the participants in which I told them more explicitly about the purpose of the article, and they did not have any objections to publication. Moreover, they got the opportunity to debrief so they could ask questions or make comments on the project and the video filming.

6 Summary of the articles and discussion of the findings

In this chapter I will first provide a summary of each of the three articles that are included in this thesis. Then, I will summarise and discuss the main findings. I will also suggest some implications for teacher education and teacher professional development, and, finally, discuss how teachers can act as change agents to develop the practice of science inquiry.

6.1 Summary of articles

The three articles included in the thesis are summarised here according to the shifts in framing at three different levels: (a) *the individual teacher* – how the teacher's beliefs bring scope and force to the practice of open inquiry in a situated practice; (b) *the science classroom* – how the teacher scaffolds the students during open inquiry; (c) *the school* – how science inquiry can be developed as a collaboration between teachers and researchers at school.

The three articles are written with different co-authors being part of the project StudentResearch. The process entailed negotiations of each author's role, different beliefs and theoretical positions. In Article I, the conception was a result of collaboration between the co-author Erik and I. Moreover, I did the interviews and the preliminary analysis, and wrote the first draft. Then we work together in an iterative process where Erik reviewed the analysis and interpretations, and also wrote some passages, and I modified the text and so on. In Article II, Stein Dankert had as a co-author the role of reviewing and providing input on the written draft; contributing substantially to the concept of the article. In Article III, Gerd and I worked close together developing the idea and the theoretical framing, moreover, analysing and reflecting over the two different action research projects. It was an iterative process where I wrote the first draft, then Gerd com provided input on the written draft, and I modified it further and so on.

6.1.1 Article I

Bjønness, B. & Knain, E. (submitted to Research in Science Education). A Teacher's Beliefs about Nature of Science: Going behind the Myths of Positivism

The purpose of this article is to understand why a positivist epistemology and related myths concerning NOS are seemingly robust in school versions of scientific inquiry even though they go against the "appropriate" views of NOS. Taking into account that school practices depend heavily upon teachers' capacity to integrate the epistemology and practices of a reform with their beliefs and existing practices, the following interrelated research questions were asked:

- *What are the experienced science teacher's espoused beliefs concerning NOS and scientific inquiry in school?*
- *Why do these beliefs represent scope and force for the teacher in a situated context with low-achieving students?*

In order to address these research questions, we draw on research literature regarding teachers' *beliefs* about NOS and scientific inquiry (Bryan, 2012; Hodson, 2009; Lederman & Lederman, 2012), as well as research on the relation between teachers' beliefs and their instructional practice (Bencze et al., 2006; S. L. Brown & Melear, 2006; Kang & Wallace, 2005). Furthermore, we draw on an understanding of teaching as dependent on *context* (Barnett & Hodson, 2001) and the teachers' *sense of identity* in their work (Nias, 1996). To understand teachers' beliefs and their importance in guiding practice, we employ Cobern's (1996) idea of worldview and consider how certain ideas have *scope* and *force* in a teacher's practice.

We analyse four in-depth interviews collected over three years to identify an upper secondary science teacher's beliefs about NOS and scientific inquiry, and how they guide his decisions in a situated context of open inquiry with low-achieving students. Data from semi-structured interviews were triangulated with reference to classroom observations and site documents from the open inquiry project. We find that what seemed to be a teacher's positivist position was embedded in a broader concern about pedagogical considerations and personal engagement with low-achieving science students. Moreover, the teacher's positive emotions toward nature and scientific inquiry were important driving forces for his practice of open inquiry. The analysis documents the importance of taking into account situated contexts and teachers' knowledge and beliefs when developing a science curriculum concerning scientific inquiry. The findings offer an understanding of how problematic and sound beliefs, from the perspective of educational research, may coexist and bring flexibilities to a teacher's belief structures. Implications for science teacher education and professional development are that teachers (students) need to reflect on personal experiences and commitments to scientific inquiry in order to become more conscious of how they affect their situated practice. Educational and personal aspects of a teacher's practice, in addition to beliefs concerning NOS, should be considered part of both the problem and solution.

6.1.2 Article II

Bjønness, B. & Kolstø, S.D. (submitted to Nordic Studies in Science Education). Scaffolding open inquiry: how a teacher provides students with structure and space

The article explores a teacher's scaffolding strategies supporting his students during a twelve-week open inquiry project at an upper secondary school. The purpose is to understand how actions of the teacher impact the nature of an open inquiry project and how they constitute the students' inquiry process. The questions guiding the case study are:

- *What were the teacher's scaffolding strategies in the different phases of open inquiry?*

- *How did the teacher's scaffolding, combining structure and space, constitute the students' inquiry process?*

In order to address these research questions, we employ research literature concerning open inquiry and how it is supposed to model professional science and provide students with the opportunity to learn essential features of scientific inquiry (O'Neill & Polman, 2004; Roth, 2012), and, moreover, for students to engage in activities to which they are committed (Hodson, 2009; Wells, 1999). However, research reveals that there are tensions between the purpose of open inquiry and the practice actually found in schools (Duschl & Grandy, 2008; Windschitl et al., 2008). Given the complexity of the process of open inquiry, it put high demands on students, as well as teachers. Scaffolding students in open inquiry involves the teacher's ability to give students a well-balanced combination of structure and space (Hodson, 2009; van der Valk & de Jong, 2009). The concept of *structure* and *space* is explored in the article, first as a theoretical proposition identifying three scaffolding structures to support different aspects of open inquiry in school, and second to analyse the teacher's scaffolding.

First, we identify the teacher's scaffolding in the different phases of the open inquiry. Then we identify emerging issues concerning how the teacher provides his students with a balance of structure and space, and how the scaffolding constitutes the students' learning experiences. The analysis is performed on video recordings from the day-to-day performance of the open inquiry for twelve weeks, focusing on the teacher's interaction with one group of students in order to obtain rich empirical data permitting in-depth analysis. The study is supported by site documents, as well as secondary data including teacher and student interviews. The case study reveals that the teacher scaffolded this open inquiry in two opposing ways: He created *space* for the students to make their own experiences and ideas, which eventually set up the need for more directed scaffolding to discuss the challenges students experienced, and he directed students' attention and ideas in certain directions in phases with *structure*. We suggest that there exists a necessary tension and interplay between structure and space, creating what can be seen as a driving force providing both exploration and direction for open inquiry. The implication for science teacher education and professional development is that the notion of 'structure and space' can work as a thinking tool to promote teachers' competence on how to scaffold more authentic versions of scientific inquiry in schools.

6.1.3 Article III

Bjønness, B. & Johansen, G. (accepted for publication in Action Researcher in Education). Bridging the Gap between Teaching and Research on Science Inquiry: Reflections based on Two Action Research Projects.

The article reports on two collaborative action research projects at Norwegian upper secondary schools aimed at developing the practice of science inquiry. The purpose of the study is to discuss how to improve the process of collaboration between teachers and researchers in order to develop the practice of science inquiry. The research question driving the study is:

How can the development of tools as a joint achievement between teachers and researchers mediate change in practice?

In order to address the research question, we use experiences from two prolonged collaborative action research projects (Herr & Anderson, 2005; Levin & Greenwood, 2001). This form of action research has the dual aim of improving a practice and contributing to the knowledge base of the relevant field. Moreover, we employ the concepts of *tools* (Engeström, 1999; Vygotsky, 1978) and *multi-voice* (Engeström, 2001) borrowed from activity theory to discuss how these concepts can complement action research strategies. We experienced in both projects two main challenges regarding the action research process: *transitioning* from the planning stages to implementation in the classroom, and not sufficiently using the *distinct voices* of the teacher and the researcher to improve practice. We do not find that these issues were greatly problematised in the literature of action research.

The two action research projects provide the examples in the article; data is collected in form of video and audio recordings from the fieldwork, reflection notes, and conversations with the participants. Moreover, we use a four-hour semi-structured interview as part of the reflections and evaluation after completion of the fieldwork. We provide snapshots from the two practices and complement them with quotes from interviews to discuss how the development of tools, as a joint achievement between teacher and researcher, can mediate change in practice. We argue that *concrete tools* for teaching science inquiry can act as an impetus for change when the development of tools is supported by educational literature as well as the situated practice. Thus the *distinguished voices* of the teacher and researcher will complement each other and might act to bridge the gap between research and practice of science inquiry.

6.2 Discussion and implications

In order to facilitate change from classroom practices characterised by teacher-centred, lecture-driven instruction toward a classroom environment that empowers young people and facilitates their intellectual development as creative and critical thinkers, we need knowledge about how change can happen in a situated school context. In a recent review, Crawford (2014) found that research is now focusing more on contextual understanding, examining how external and internal barriers concerning school science inquiry have implications for teacher education and teacher development. Moreover, painting portraits of inquiry practices in a variety of settings is needed (Crawford, 2014; Keys & Bryan, 2001).

This thesis is a contribution to this agenda though an in-depth and longitudinal study of teachers' beliefs and practice of open inquiry. The school context with low-achieving students is of interest as it plays a significant role in the teachers' interpretation of the inquiry practice. I will start by discussing the main findings from the study, then I will discuss implications for teacher education and professional development, as well as how teachers' collaboration with peers and experts can provide new understandings and contribute to the development of school science inquiry in a situated context.

6.2.1 Major findings from the study

Open inquiry has been suggested as a way to enhance more authentic science learning, providing students with their own experience of inquiry to learn about NOS and scientific inquiry (Duschl & Grandy, 2008; Roth, 2012; Wells, 1999). However, it is also suggested that open inquiry is a mode of instruction that is simultaneously hands-on for students and hands-off for teachers, drawing parallels to discovery learning (Kirschner et al., 2006; Settlage, 2007).

Findings from this thesis can broaden our understanding on how a teacher's scaffolding of an open inquiry project constitutes the students' learning process. In Article II, the day-to-day analysis of a 12-week open inquiry project revealed that it was extensively scaffolded by the teacher, in contrast to a view of open inquiry as a version of discovery learning. We found that the teacher used several scaffolding strategies within the following three groups: (1) scaffolding that makes the essential features of scientific inquiry explicit; (2) scaffolding that structures complex tasks or reduces cognitive load; and (3) scaffolding that facilitates phases with space for student autonomy. Moreover, we found that the students learned to ask questions regarding a natural phenomenon of their own interest; create a research design; perform experiments and collect data; and present their findings. The students worked more and more autonomously during the inquiry process, asking questions and solving problems within the groups, being both creative and critical toward their own work. Thus, they learned some important features of scientific inquiry (Lederman & Lederman 2012). However, the open inquiry in the present study was also characterised by a step-by-step method and a lack of theoretical framing to inform the students' research design, as well as the discussion of results, implying that it represents a simplistic version of scientific inquiry, often called "the scientific method" in science education literature (Duschl & Grandy, 2008; Windschiltl, 2004, 2008).

This finding resonates with international research on open inquiry, revealing that school versions of scientific inquiry often are not "adequate" for students to develop contemporary views about NOS and scientific inquiry (ibid.). Moreover, the present study supports to some extent the existing research revealing that science teachers often show positivist beliefs about NOS; tending to ignore the role of theory, belief in a step-by-step method, and a tendency to overlook the socio-cultural embeddedness of scientific practice and role of creativity (Bryan, 2012; Hodson, 2009; McComas, 1998). Despite a massive interest in NOS over the last 20 years, research continue to reveal that teachers show epistemologically naïve views of NOS, and practices of scientific inquiry in schools do not reflect a contemporary view on NOS. In order to understand why these simplistic versions of scientific inquiry continue to rule in schools, we sought to go behind the myths of positivism (McComas, 1998), to explore why they provide *scope* and *force* in a science teacher's practice.

In Article I, we used an in-depth and longitudinal analysis to discover three emerging dimensions providing scope and force for a teacher in his situated practice: (a) his epistemological beliefs about NOS and scientific inquiry, (b) his pedagogical considerations about students with low interest and achievement in science, and (c) his own personal experiences and emotions relating to nature and scientific inquiry. These findings suggest that in order to understand why a positivist ideology concerning NOS is seemingly robust in school versions of scientific inquiry, we must consider the teacher's *broader ecology of belief*, in addition to *emotions* toward nature and scientific inquiry.

We found that Amir regarded the open inquiry project as purposeful for students struggling with science, even though it went against "appropriate" views of NOS. What represented scope and force for him was to provide the students with opportunities for asking their own questions and getting first-hand experience of a natural phenomenon, thereby promoting pleasure and positive attitudes toward science. In addition he saw the open inquiry as a way to opposing rote learning from the textbook. We found that the teacher's *positive emotions* toward exploring natural phenomena came from his own childhood identity as a "little scientist", and represented a driving force for his practice of open inquiry.

Moreover, the teacher's focus on "the scientific method" reveals a positivist position: Students can inquire about just anything using "the scientific method" – nature will correct their understanding if not correct. However, we found when analysing Amir's beliefs about NOS in the situated practice that the simplified step by step method rather represented his *pedagogical considerations*; a way to scaffold complex task and reduce cognitive load taking into account these students' history of failing in more academic subjects like science. It can perhaps also be explained by the use of "the scientific method" that is commonly found in textbooks and in the science education community (Chinn & Malhotra, 2002; Knain, 2001). This scaffolding strategy is problematic, taking into consideration the conflation between "the scientific method" as a scaffolding structure and as a model of scientific inquiry. However, findings from students' presentations and interviews indicate that the students' own experiences from the process of open inquiry made them understand some of the complex and uncertain nature of scientific inquiry, as asserted by O'Neill & Polman (2004). However, the students' written reports from the project did not reveal this understanding of the complexity of scientific inquiry. This indicate that the students had an *implicit* understanding of the complex nature of the process, and that there probably is a potential for scaffolding that supports more *explicitly* the essential features of scientific inquiry to improve students' learning from performing their own inquiries.

Perhaps the most problematic issue revealed by the interaction analysis in Article II was the lack of scaffolding from the teacher concerning *how* to use relevant theory to inform the inquiries. We found that most of the students did handle theory as a separate entity, following the teacher's scaffolding. Thus, the open inquiry might have resulted in students believing that theory-independent observation and evidence is obtainable, a problematic tenet of inductivism (Duschl & Grandy, 2008; Lederman & Lederman, 2012). The teacher's espoused beliefs suggest that it provided scope and force for him to downplay the role of theory in the students' project and focus more on their personal relation to the phenomenon through first-hand experiences. We found that the strategy was related to the teacher's *pedagogical consideration* of these students struggling with academic subjects at school. However, science "as a way of knowing" is moving away from a view that emphasises observations and experimentation and toward a view that stresses theory, model-building, and revision—in other words, a view of evidence obtained from theory-driven observations (Driver, Newton, & Osborne, 2000; Duschl & Grandy, 2008). The question that arises is then the use of time in school science classes that should be allocated to interactions with basic scientific phenomena. This will be further discussed in the Section 6.2.2 concerning the implications for the practice of open inquiry.

Findings from this study also provide us with a broader understanding about the congruency between teachers' beliefs concerning NOS and their classroom practice. Research reveals that the relationship between teachers' pedagogical decision-making and their beliefs about NOS is not straightforward (e.g., Benze et al., 2006; Brown and Melear, 2006; Kang and Wallace, 2005; Mansour, 2013). The present research shows that there was coherence between the teacher's purpose and goal of inquiry and the implementation of this purpose and goal in the classroom. However, the teacher hold sophisticated beliefs about NOS that were not reflected in the practice of open inquiry, especially concerning his presentation of "the scientific method" and the lack of support on the theoretical framing of the inquiry process. This correlates with the findings of Kang and Wallace (2005), revealing that a teacher's sophisticated epistemological beliefs are not always clearly connected to his or her practice. Our findings can offer an understanding of how problematic and sound beliefs, from the perspective of educational research, may coexist and bring flexibility to the teacher's belief structures. The finding suggests that a valuable approach to improve practice and obtain more robust versions of scientific inquiry in school is to include the teachers' identification of their own *broader ecology of beliefs* and *emotions*: how they inform, expand and limit possibilities within a situated practice.

Findings presented in Article II reveal that the scaffolding of the open inquiry project was complex and demanding, and this resonates with research showing that open inquiry put high demands on the teacher (Bencze et al., 2006; Crawford, 2000; Zion & Slezak, 2005). Dewey (1938) also underlined that basing education upon personal experiences may mean more multiplied and more intimate contacts between the students and the teacher, and thus more rather than less guidance. The idea that student-active teaching methods are necessarily hands-off for teachers can perhaps be left behind. Rather, student-active teaching approaches require that the teacher must in some way *balance* the amount of guidance—not providing too little guidance, leaving students unable to make satisfactory progress, but not giving too much, interfering with students' thought processes (Dewey, 1938; Hodson, 2009; van der Valk and de Jong, 2009). Students need *structure* to help organise and direct their own inquiry, and to support essential features of scientific inquiry and conceptual understanding (Asay & Orgill, 2010; Windschitl et al., 2008); they also need *space* to experience situations requiring creativity and critical thinking, and reasoning skills (Hodson, 2009; Wells, 1999; Zion & Slezak, 2005).

In Article II, we offer understanding through detailed descriptions from the situated inquiry practice revealing how a teacher combines structure and space and the consequences for the students' inquiry process. We found that the teacher used the steps in the "the scientific method" to provide *structure* for the inquiry process and simultaneously allowing space for the students to introduce their own ideas and thoughts within these limits. Moreover, we found that the teacher scaffolded the open inquiry in two opposing ways; he created *space* for the students to make their own experiences and ideas, which eventually set up the need for more directed scaffolding to discuss the challenges the students experienced, and he directed students' attention and ideas in certain directions in phases with *structure*. The scaffolding provided tension and interplay between "structure and space" as a driving force for both exploration and direction for open inquiry. In Section 6.2.2, I will provide a model for "structure and space" and how it can work as a "thinking tool" for teachers' planning of open inquiry.

Even though there is research revealing that open inquiry is not some kind of discovery learning as asserted by Settlage (2007), I agree with him that science teachers and science educators might easily be the target of derision by anti-progressive policymakers because of statements such as "students are turned loose as investigators". This situation is reflected in the Norwegian discourse as well; the implementation of inquiry has been discussed, especially in connection with the Norwegian PISA results showing a negative correlation between inquiry approaches and learning outcome (Kjærnsli et al., 2007). This has clearly influenced the Norwegian debate, in which inquiry is being put forward as some kind of unguided discovery, even though very little is known about what forms of inquiry and teacher scaffolding are behind these PISA results. However, recent international research suggests that inquiry approaches yield the same or better outcomes than traditional teaching approaches (see, Cobern et al., 2012; Crawford, 2014). Thus, the question is perhaps not if inquiry "works"; rather, the important questions should be, as suggested by Hmelo-Silver and her co-authors (2007), under what circumstances does inquiry work, what kind of valued practice do inquiry promote, and what kind of support and scaffolding are needed for different students with different learning goals?

To sum up, we found that an open inquiry learning environment inspires young people who are struggling with motivation for science, and that they can gain knowledge about the processes of scientific inquiry. This correlates with other findings from research on low-achieving students in an open inquiry environment (Lee et al., 2006; Yerrick, 2000; Yerrick et al., 2012). However, findings in the present study also reveal that the students' conceptions about key features of NOS, especially concerning the role of theory in scientific inquiry, were probably not learned from performing their own inquiry. The findings resonates with some empirical research on open inquiry (e.g., Bell, Blair, Crawford, & Lederman, 2003; Windschitl, 2004) while it represents a contrast to other empirical research on open inquiry revealing more sophisticated versions of inquiry (e.g., O'Neill & Polman, 2004; Sadeh & Zion, 2009). In the science education community it is questioned whether it is possible to couple teaching *with* and *about* NOS (Abd-El-Khalick, 2012). The present study reveals, in concert with relevant research (see Crawford, 2014), that the goal of helping the students to develop informed conception of NOS and experience inquiry that model authentic scientific practice is demanding for teachers. We assert that in order to obtain robust versions of scientific inquiry in school it is necessary to help science teachers to develop their understanding of NOS based on the individual teacher's *broader ecology of beliefs*; thus, epistemological beliefs about NOS and scientific inquiry, pedagogical considerations, and personal experiences and emotions relating to scientific inquiry. Moreover, the present findings indicate that the notion of "*structure and space*" can work as a tool for teachers to plan open inquiry that facilitates a fruitful combination of students own experiences and explicit-reflective guiding concerning essential features of NOS and scientific inquiry.

6.2.2 Implications for teacher education and teacher professional development

After several decades of research on school science inquiry and continuous efforts in schools, teachers still find it difficult to put inquiry into practice, and it is not commonly found in schools (Asay & Orgill, 2010; Capps & Crawford, 2012; Bencze, et al., 2006). However, I do agree with

Crawford (2014) that highlighting the teacher as the central factor to obtain more sophisticated versions of science inquiry in practice, is not meant as a disparagement to teachers. Anyone who has carried out science inquiry in a classroom knows that it is a complex and demanding teaching approach.

In Article I, findings indicate that in order for teachers (students) to prepare for and develop their practice of inquiry in school, they need to identify the broader ecology of beliefs and emotions that impact and drive their actions and reactions; they also need to be able to alter these beliefs and emotions, as well as becoming aware of strengths on which to build further development. This emphasises the value of teachers (students) spending time on a productive inward journey in the process of developing their professional identity (Beijaard, Meijer, & Verloop, 2004; Nias, 1996). I will provide an example from a teacher education class in South Africa, reported by Hattingh & De Kock (2008): The university teachers ask the beginning teaching students individually to create a visual collage using, for example, glossy magazines to portray their perceptions of teacher roles. This introspective reflective activity is followed up by sharing their perceptions, and it becomes possible to identify the existing perceptions of teacher roles, linked to a personal educational belief system that has an impact on their teaching identity. This activity is followed up after practice in school. The authors found that the teacher education program, with a strong focus on teacher-as-self, had challenged the traditional roles that the student teachers saw themselves fulfilling (ibid.). Moreover, there is strong support for teacher education and professional development programs putting weight on combinations of rich inquiry experiences followed up by explicit reflections about essential features of NOS and scientific inquiry (e.g., Abd-El-Khalick, 2012; Lederman & Lederman, 2012). These guided reflections might as well challenge teachers' beliefs and tacit frameworks of what it means to perform scientific inquiry in a situated practice.

In Article II we found that the teacher provided the students with a simplified step-by-step version of scientific inquiry described as "the scientific method". However, Duschl and Grandy (2008) propose in their recommendations for research and implementation of science inquiry in schools that the oversimplification of the scientific method should not be rejected without understanding it. Their suggestion is, rather, to radically supplement it. An important question is then how to sustain the students' enthusiasm from first-hand experiences of natural phenomena *and* include theory to inform the inquiry. This was one of the main issues that we discussed in the action research project. Amir wanted to implement an overarching theme for the whole class, providing possibilities for more guiding on relevant theory and discussions among the entire class. Unfortunately, he fell back on a known practice in which students asked their own questions concerning a wide variety of phenomena. The reason for this was, according to Amir, that the students showed little interest and did not manage to come up with a common theme to explore. This indicates that, in order for change to happen, the scaffolding tools to develop a practice must be robust, and they must resonate with the teacher’s beliefs about what works. The choice of an overarching question or theme—this is actually also what Dewey suggests—will provide the teacher and students with more opportunities for explicit reflections, and will make it easier for the teacher to support the students on *why* and *how* to inform their inquiries with relevant theory. The idea of open inquiry in which the students choose a phenomenon of their own interest puts very high demands on a teacher in order to scaffold many different research designs and theoretical frameworks, depending on the subfield of science. From three years of action research, we experienced that a theme like, for example, “quality of drinking water in the local community”, seemed to be of interest for many of the students in this case, and provided opportunities for more “permeable” classrooms (Jarman & McClune, 2007) to build a bridge between school and the world outside, and make the inquiries more relevant.

Another approach to a more sophisticated version of open inquiry is the “research meetings” suggested by the researchers in the project. This approach was implemented by me in the second cycle, and by Amir in the third cycle. The scaffolding tool of a “research meeting” draws on two theoretical positions: (1) socio-cultural perspectives of oral language as a vehicle for students’ understanding of the inquiry process and (2) peer-review processes in “professional” science to assess and argue for methods and results. The implementation of “research meetings” in Amir’s and Bernard’s classes showed promising results and is the focus of an article in process. It represented a milestone in the students’ work and an arena for students to discuss experienced problems; it also allowed for explicit guidance from the teacher (and peers) on relevant features of inquiry.

In order for teachers and student teachers to plan and prepare for open inquiry in the classroom, we believe that the notion of “structure and space” can enhance their competence to scaffold more authentic scientific inquiry, as well as promoting active and autonomous learning. Findings from Article II reveal that there exists a necessary interplay and tension between structure and space, creating what can be seen as a driving force providing structure, content and directions for the students’ own experiences from open inquiry.

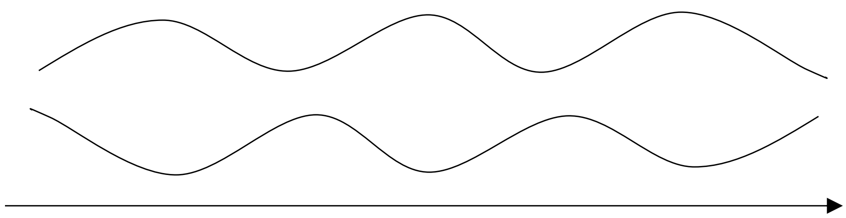


Figure 4. Scaffolding of the process of open inquiry, alternating between ‘structure and space’

The model can be seen as a “thinking tool” for teachers (students) planning and reflecting on how to combine structure and space to scaffold the open inquiry to support essential features of scientific inquiry. For example, the teacher needs to plan for explicit support (*structure*) on how to use theory to inform the research design; in this case, the teacher could provide a scaffolding structure (read relevant literature, ask experts, detect relevant parameters, etc.) that lead the students to make their own challenging experiences (*space*), trying to understand how it can inform their research design. The following structured phase (e.g., teacher guidance) then attracts students’ interest when it focus on challenges the students have experienced in open phases. This dynamic model of “structure and space” might help increase the synergy between what Abd-El-Khalick (2012) calls the “lived” (doing) and “reflective” perspectives of scientific inquiry, providing more robust inquiry learning environments. Moreover, the “thinking tool” can become valuable in supporting teachers’ (students) collaboration to improve science inquiry. The tool can help facilitate the exploration and negotiation (Engeström, 2001) of how to scaffold the students’ inquiry process depending on the learning goals – providing both “structure and space”. The use of diagrams/tools also allows for the teachers to slow down the pace (Furberg, Kluge, & Ludvigsen, 2013) and spend considerable time on planning, which is vital to create more robust versions of open inquiry.

6.2.3 Teachers as change agents to develop practice of science inquiry

The reflective and innovative teacher is an important change agent in the shift from a traditional to a more inquiry-oriented classroom. In order to improve and develop inquiry in school science, there is now a movement from research *on* practice—implementing teaching units—toward research approaches where researchers work *with* teachers to develop practice and knowledge as a collaborative effort. Lederman and Lederman (2012) claim that little research is done concerning the role of professional development in facilitating change related to NOS and scientific inquiry. The prolonged action research project provides insight into constraints and possibilities in the process of developing practice of inquiry school science. Thus, I will suggest some implications for collaborative action research, which might be relevant for teacher network as well.

In Article III, we discuss how the research domain can support the development of teaching practices and how situated teaching can provide important perspectives into educational research. The approach offers professional development in the sense that teachers rarely get the time to see the “whole picture” of their practice, and many live isolated from research findings and theoretical debates about key issues in science education (Hodson & Bencze, 1998). In the article we argue for the concepts of *multi-voice* and *tools* (Engeström, 1999, 2001; Vygotsky, 1978) as useful supplements to collaborative action research to challenge an established practice. The multi-voice is then connected to the distinct voices of the teachers and researchers due to different roles, positions and focus. Furthermore, the multi-voice also raises the awareness of relevant theory as a significant voice itself and contributes to the aim of collaboration. However, to take advantage of multi-voice, there needs to be trust (Grant et al., 2008) and sameness (McArdle, 2008) in the relationship between teachers and researchers. This is especially important since educational practices are closely connected to the teacher as a person (Barnett & Hodson, 2001). Moreover, a teacher must perceive that the change in practice is manageable to carry out and beneficial for the students; thus, the negotiation between teachers and researcher must be based on the situated classroom practice. We propose that the *joint development* of *concrete tools* to mediate the change in classroom activities can overcome teachers' resistance to change, and explicate the researchers' intentions. Working together designing tools for use in the classroom might also be a way to avoid patronising teachers. In addition, the process of translation between teachers and researchers explicating their ideas can be seen as a possibility for professional development (for both teachers and researchers). We argue that in order for teachers not to fall back on known practice in the rough and tumble of the classroom, the tools for mediating practices in the classroom need to be *concrete, robust and made and re-made* to fit the situated practice.

In Norway, as part of the Knowledge Promotion school reform, the subject curricula were developed to leave room for local curriculum development to take place. Moreover, the teaching profession should be strengthened through the anticipation of teachers developing local curricula and assessments in accordance with the national goals (Aasen et al., 2012). The development of local curriculum provides possibilities, but it is also demanding for teachers. The findings of the thesis emphasise the importance of understanding how teachers invest themselves and their sense of identity in their work (Nias, 1996). A creative and reflective teacher is necessary for developing teaching in a situated practice, and collaboration with other teachers and researchers can be valuable in providing new insights and empowering the teacher.

6.3 Final comment

In my opinion we need to facilitate change toward a science classroom environment that empowers young people through facilitating critical thinking, creativity, communication and collaboration, skills that are essential for democratic participation and sustainable development (Binkley et al., 2012; Sinnes & Eriksen, 2014). This calls for more student-active approaches like inquiry, in which students ask their own questions and struggle to solve problems. However, in the case of open inquiry, it is demanding for teachers to scaffold and difficult for students to perform and takes time, and it is therefore also important to address issues concerning learning outcomes and effectiveness.

The reflective and innovative teacher is a key factor for change in schools. “Top-down” regulations to improve schools often fail, and teachers need to be involved and influence the development taking account of the situated practice. Future research on effective teacher education programs and professional development taking into consideration internal barriers (teacher knowledge, beliefs and views) and external barriers (schools context and school culture) seems to be vital for inquiry to be successfully enacted in the science classroom. Moreover, teachers (students) need reform-based education experiences to foster beliefs that teaching science as inquiry is important and possible in the reality of the classroom.

Hopefully, this thesis will contribute to expand our knowledge about possibilities and constrains related to teachers’ support of students learning from open inquiry in the classroom. Moreover, I hope that the empirical research will be useful as “real-life cases” for discussing barriers in teaching and learning scientific inquiry from open inquiry. Hopefully, the thesis can also contribute to the understanding of how collaboration between teachers and researchers can help to bridge the gap between practice and theory of science inquiry in school.

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Appendices

Appendix I: Interview guide - Amir (December, 2008)

The open inquiry project

- How did you experience the start of this year open inquiry project?
- What do you put weight on when you introduce scientific inquiry for your students?
- Is it something that you find especially important to teach in the introduction phase?
- The students are encouraged to use natural phenomena as a starting point – other sources of inspirations?
- Do you see any role of collaboration, argumentation and critical evaluation the in knowledge building process?
- How did you get the view of nature of science that you have today?

Learning outcome and the curriculum

- What expectations do you have for students learning outcome from the project?
- What are your thoughts about the main area “the budding researcher”?
- Should the students use the science curricula as a point of departure for their projects?
- Do you consider making it an interdisciplinary project? And with what subjects?

Frames

- Do you feel that you have support among your colleagues concerning the project?
- Do you feel that you get support from the school management?
- What do you expect from the school management?
- What is the time frame of the project?

History

- How did you get the idea for the project?
- Motivation?
- How has the open inquiry project changed in character during the years?
- How has your attitude to the project changed during the years?

Appendix II: Interview guide – teachers (Amir, Berit, Bernhard) (April 2008)

The open inquiry project – challenges and possibilities

- How was your experience with the project?
- What worked and what did not work?
- Can you explain how you organized the project for your students?
- Is it something you want to do different next year?
- What are the possibilities in an open inquiry project compared with practical work?

The teacher role in the project

- What was motivating for you implementing open inquiry?
- What were your roles as a teacher in the project?

Learning about scientific inquiry

- Do you find that there is a connection between the students performing of open inquiry and scientific research?
- What do you feel was the most important the students learned from the project?
- Did the students manage to use relevant theory when discussing their results?
- How did the students collaborate in their groups?

Support

- How was the collaboration with the other teachers?
- Did you get sufficient support from the school management?

Appendix III: Interview guide – Amir (June 2010)

1. Short summing up from this year's project
   - Exam, challenges, students learning…

2. How did you plan supporting the students' learning from open inquiry this year?
   - Overarching frame
   - Scaffolding structures
   - Analysis and interpretation
   - Presentation and report

3. What characterize your role as a teacher during open inquiry?
   - Mentor, supervisor, motivate, evaluate, model
   - Creativity, flexibility, encouragement, trust, time

4. How do you adjust scaffolding structures and guiding to different students and groups?

5. Assessment
   - Formative
   - Summative

6. "Space and structure" – show Amir the model
   - What do you think about it
   - How can it be used

7. Some students tell that they wanted more support on how to use theory, to ask good questions and to interpret the results.
   - What are your thoughts about that?
   - How is that possible to achieve?

8. Go through the scaffolding structures and guiding in order to see if we have a common understanding of what it was in the project:
   - Process, learning platform, small activities (focus), research meetings, assessment criteria, poster, report

Appendix IV: Interview guide – Amir and Ellen (teachers), Gerd and Birgitte (PhD-students) (June 2010)

1. The teachers present the projects at the individual schools

2. How did you experience being a participant in a collaborative action research process?
   - To get researchers into the classroom
   - Interaction and collaboration with researcher
   - To be filmed and interviewed
   - The "double burden" – the science inquiry and the action research

3. How did you experience being a PhD-student doing action research?

4. How did the school's frames influence the action research project?
   (e.g., school management, timetable, curriculum, meeting time, equipment, colleagues, students)
      - What has been good?
      - What has been problematic?

5. "Dream workshop": how can we describe the ideal meeting between school, teacher and researcher to develop school/curriculum?
   - Trust, who owns the "case", who should lead the process, believe in a common project, development of personal relations, the role of school

Appendix V: Interview with the "hair-group" (May, 2010)

Part 1 Generally about working with open inquiry

- What expectation did you have to the project?
- Was it different than expected? Why?
- Three words that describe the emotions you had during the work with the project?
- Can you describe your inquiry process?
- What did you learn from working with scientific inquiry?
- Similarities/differences from other practical work in the natural science subject?
- What could have been done differently?
- What recommendations do you have for next year's students (explain why)?

Part 2 Guiding and scaffolding

- What information did you get from the teacher before, during and after?
- How did the teacher's guidance work?
- Collaboration with the teacher (describe a good meeting)?
- Was it you or the teacher that took initiative for guidance?
- How did the guiding work in the different phases of the project? Provide concrete examples (why and how).
- How did you use the template on the learning platform? (structure and learning process)
- Do you have examples of critical moments in which guidance from the teacher was particular important?
- How did you experience the research meetings?
- Did you use the assessment criteria?
- How did you experience the evaluation of the exhibition?
- What can teachers do to support students learning during the open inquiry project?

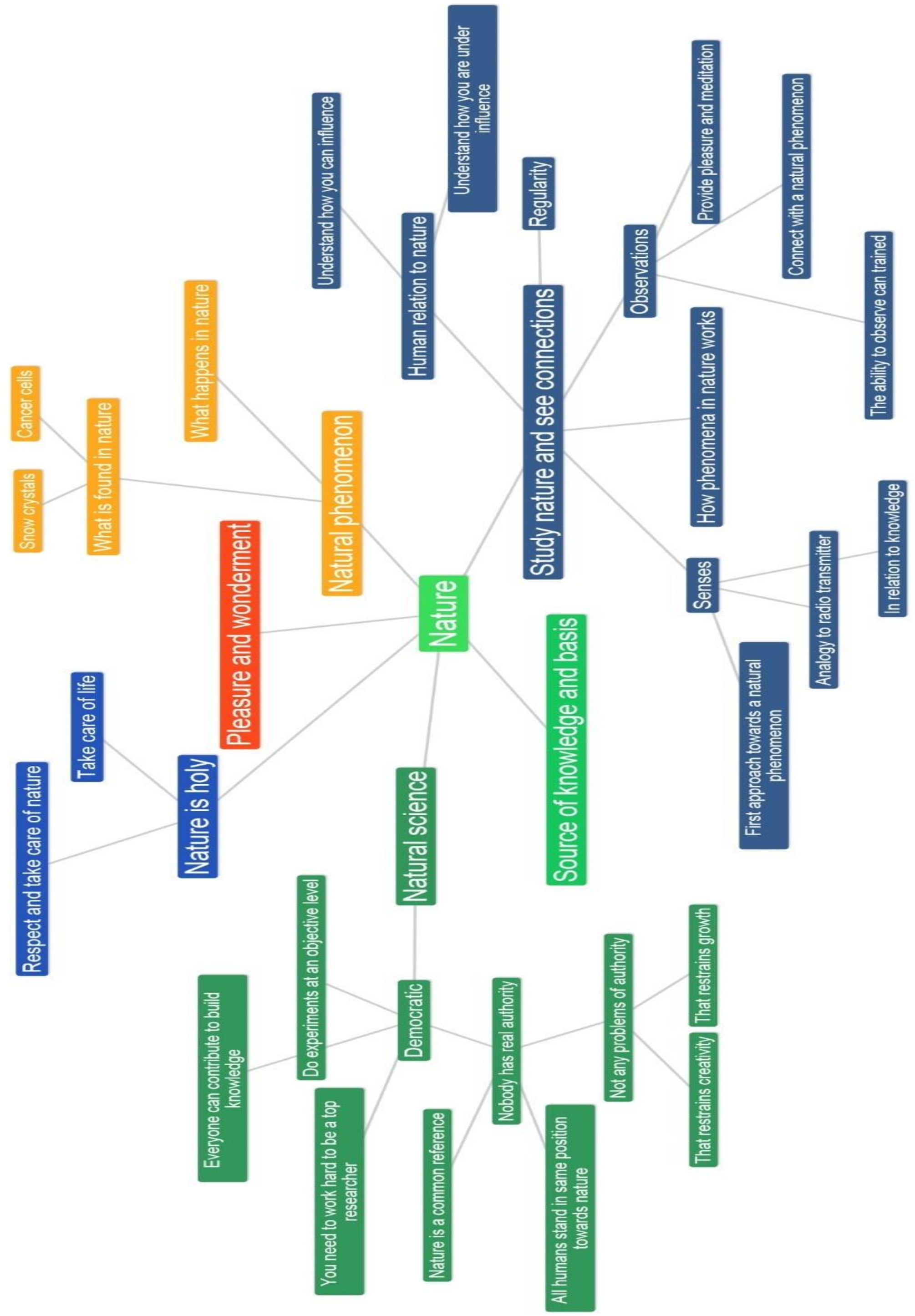
Part 3 Learning from the open inquiry project

- What was the result of your inquiry?
- Why did you want to study this phenomenon?
- Did you use any theoretical sources? What? How?

Part 4 Collaboration

- How did the collaboration work?
- Division of labour?
- What was your role in the collaboration?
- Did the collaboration contribute to the inquiry process?
- How did you solve disagreement?

Appendix VI: Example of mind-map as visual thinking tool



PART II:

THE ARTICLES

A Teacher's Beliefs about Nature of Science: Going behind the Myths of Positivism

Birgitte Bjønness and Erik Knain

Abstract

Changes in school practices depend heavily upon teachers' capacity to integrate the epistemology and practices of a reform with their beliefs and existing practices. One of the major concerns relating to teaching scientific inquiry is that many teachers show epistemologically naive beliefs about nature of science (NOS). In this case study, we use in depth interviews to identify an upper secondary science teacher's beliefs about NOS and scientific inquiry in school, as well as how they guide his decisions and actions in situated practice with low-achieving students. The purpose is to understand why positivist epistemology and related myths concerning NOS are seemingly robust in school versions of scientific inquiry. We found that what seemed to be a teacher's positivist position was embedded within broader concerns regarding the pedagogical considerations and personal engagement relating to the group of students. Moreover, the teacher's positive emotions towards nature and scientific inquiry were important driving forces for his practice of inquiry. The implications for science teacher education and teacher professional development are that teachers need to reflect on personal experiences and commitments towards scientific inquiry to increase conscience with respect to how they affect their practice. Educational and personal aspects of a teacher's practice, in addition to beliefs concerning NOS, should be considered part of both the problem and solution.

Keywords: teacher beliefs, nature of science, scientific inquiry, upper secondary school

Introduction

Reforms in science education all over the world advocate a view of teaching and learning science that emphasises inquiry to learn about nature of science (NOS) and increase interest in science (e.g., European Commission 2007; National Research Council 2000). Taking into consideration the key position teachers hold in shaping the teaching practice and students' learning environment (Keys and Bryan 2001), the desired change in school science depends heavily upon teachers' capacity to integrate the epistemology and practices of a reform with their beliefs and existing practices (Bryan 2012).

However, despite a massive interest in NOS over the last 20 years, research continues to suggest that many teachers show epistemologically naive views of NOS (Lederman and Lederman 2012). In a literature review regarding teachers' views of NOS, Hodson (2009) points to some generally perceived weaknesses of these views, which include ignorance of the theory-laden nature of observation and experimentation, belief in a fixed algorithmic method of scientific inquiry, uncertainty about the status of scientific knowledge, the tendency to overlook the socio-cultural embededdness of scientific practice and the role of creativity and imagination. Together this constitutes a "positivist" view of science where empirical inquiry is reduced to a process of "reading the book of nature" where the crucial significance of argumentation in scientific communities in the construction of scientific knowledge is downplayed (Driver, Newton, & Osborne, 2000). The relationship between teachers' beliefs about NOS and their pedagogical decision making is not straight forward (Bryan 2012; McComas et al. 1998; Nasser 2013). Nevertheless, research reveals that oversimplified versions of scientific inquiry are common practice in school science (e.g., Capps and Crawford 2012; Grandy and Duschl 2008; Windschitl 2004).

According to Keys and Bryan, we have "little knowledge of teachers' views about the goals and purposes of inquiry, the processes by which they carry it out, or their motivation for undertaking a more complex and often difficult to manage form of instruction" (2001, p. 636). Can the broader ecology of teachers' beliefs help to explain what makes simplistic versions of scientific inquiry purposeful in teaching even though they go against the "appropriate" views of NOS? Towards this end, we believe that we must consider why they represent scope and force for teachers in their situated and complex practice.

The paper is based on an analysis of an experienced science teacher's beliefs, as well as how they guide his decisions and actions in a practice of open inquiry at a Norwegian upper secondary school with low-achieving students. The purpose of the study is to understand why a positivist ideology and related myths concerning NOS are seemingly robust in school versions of scientific inquiry.

The study is guided by two research questions. Firstly, what are the experienced science teacher's espoused beliefs concerning NOS and scientific inquiry in school? Secondly, why do these beliefs represent scope and force for the teacher in a situated context with low-achieving students?

Teachers' Beliefs Concerning Teaching and Learning about NOS

Examining teachers' beliefs can provide insights into the types of experiences that teachers provide in their classrooms. In a review of teachers' beliefs and educational research, Pajares (1992) reported that beliefs are personal constructs that strongly affect individuals' behaviour and that the "belief system has an adaptive function in helping individuals define and understand the world themselves" (1992, p. 325).

Much research has investigated teachers' beliefs concerning NOS, and it appears that a positivist ideology is commonly held among science teachers (Bryan 2012; Hodson 2009; Lederman and Lederman 2012). Furthermore, some research suggests congruency between teachers' beliefs about NOS and their instructional practice (e.g., Bencze et al. 2006; Brickhouse 1990), while other research show no significant relationships between teachers' understanding of NOS and their practice (e.g., Brown and Melear 2006; Kang and Wallace 2005). The latter seemed to be especially true for teachers holding sophisticated views of NOS, but who did not apply it in their teaching practice (Kang and Wallace 2005).

Likewise, pre-service teachers' informed understanding of NOS does not necessarily lead to a sound practice at school. For example, in a three-year longitudinal study of five early career science teachers and their beliefs about teaching, Fletcher and Luft (2011) found that the new teachers' beliefs tended to move from a contemporary position while participating in their teacher training program toward more traditional beliefs about teaching through practice in school. They suggest that the shift can be caused by beginning teachers facing situations such as a static school culture, little support from school leaders for implementing reform-based strategies and the new teachers' feelings of being overwhelmed with teaching. However, some research reveals factors that seem important developing in-service and pre-service teachers' understanding of NOS; notably providing teachers with their own experiences of inquiry, as well as explicit opportunities for reflection about NOS (e.g., Ozgelen, Yilmaz-Tuzun, & Hanuscin, 2012; Schwartz, Lederman, & Crawford, 2004).

Open Inquiry as a Context for Learning about NOS

Open-ended scientific inquiry projects has been suggested by numerous researchers to replace recipe-type experiments in order to enhance and enable more authentic science learning (Duschl and Grandy 2008; Roth and Bowen 1995; Wells 1999). Moreover, open inquiry is supposed to provide the students with opportunities to learn about essential features of scientific inquiry and NOS through own experience (Asay and Orgill 2010; Zion et al. 2004; Bencze et al. 2006). The problem is that the open inquiry approaches presented in school science are mostly simplistic versions of the scientific method, and they obscure the complex methodological strategies found in real science (Windschitl 2004; Grandy and Duschl 2008).

In research involving six pre-service secondary teachers, Windschitl (2003) found that teacher students using open inquiry in their teaching practice were not those with more sophisticated understanding of scientific inquiry, but rather those that had their own experience of authentic science research. In a later study, Windschitl and Thompson (2006) found that participants in a student course aiming at increasing students' model-based reasoning continued to use simplistic forms of "the scientific method" as a procedural framework for thinking about inquiry, despite the instructors repeatedly pointing out its oversimplified and unauthentic nature.

Teaching as Context-dependent

The students in the present study can be seen as low-achieving students in academic subjects such as science. Research on school science in contexts with low-achieving students reveals that there is a tendency to concentrate teaching on achieving only basic factual science information based upon rote learning (Yerrick et al. 2012). However, research on inquiry-based learning in lower-track contexts (Yerrick 2000) has shown that students received new insight into what it means to understand science. The author argues that "asking students to learn more of the same things in the old ways serves only to perpetuate their naive beliefs and indifference about the nature of science itself" (p. 832).

Barnett and Hodson (2001) further suggest that development of the curriculum very often fails because education is looked upon in a decontextualized way. In contrast to this thinking, they propose that we must acknowledge teaching as a complex and uncertain enterprise.

> To signify that what good science teachers know, do, and feel is largely about teaching, and is situated in the minutiae of everyday classroom life (...). The sources of this knowledge are both internal and external: internal sources include reflection on personal experiences of teaching, including feelings about the responses of students, parents, and other teachers to one's actions; external sources include subject matter knowledge, governmental regulations, school politics and the like. (p. 436)

In accordance with this complex way of viewing teaching, a teacher may hold a specific epistemological position, not only because of his/her epistemological beliefs, but also because of needs such as instructional goals and classroom management (Kang and Wallace 2005).

Furthermore, teaching is seen as inextricably linked to teachers' personal lives. Teachers invest themselves and their sense of identity in their work (Nias 1996). According to Zembylas (2002), there is a widespread belief that emotions are a central aspect of education and teaching. The author promotes "identifying how science teachers' emotions inform, expand or limit possibilities in their science teaching and how these emotions enable them to think and act differently" (p. 97). Thus, teachers' stories about their emotions can become important for changing the ways science teachers interpret educational matters and become a productive starting point for action (Nias 1996; Zembylas 2002).

A complex understanding of teaching also takes account of the students' personal understandings. Cobern (1996) uses the concept of worldview to explain that every individual has a set of fundamental presuppositions and that his or her perception of reality is grounded on these. Cobern suggests that for school science to be meaningful, teaching must fit the students' sense of self, environment, personal goals and their understanding of how the world really is. A concept or belief has *force* if it is central in an individual's thinking rather than marginal, and it has *scope* if it has relevance for the individual over a wide range of contexts. To understand teachers' beliefs and their importance in guiding their practice, we draw a parallel to Cobern's idea of worldview and consider why certain beliefs have scope and force in a teacher's practice. In teacher professional development or teacher education, the teacher (student) may accept explicit instructions about NOS as a valid approach, but these instructions about NOS may still contradict deeply held commitments regarding NOS and what constitutes good and appropriate teaching practices.

Previous research has found relationships between teachers' beliefs and inquiry practices, and moreover these beliefs are found to be significantly at odds with accepted NOS tenets. However, beliefs need not be consistent with practices. Our study takes as point of departure that courses of actions are grounded in a web of belief structures, not necessarily consistent, related to important concerns regarding Nature, teaching, students, and learning. Specific beliefs, regarding for instance NOS, gain their scope and force in this broader ecology of beliefs.

Method

The case study presented in this paper draws upon experiences from fieldwork over three years at an upper secondary school. It is an in-depth study of an experienced science teacher (Amir), and his implementation of a twelve-week open inquiry project with low-achieving students. We follow Flyvbjerg (2011) in that single-case studies can be of great importance since they produce concrete, rich, context dependent knowledge, thus increasing our understanding of what causes a phenomenon. In this case we have chosen to follow an experienced and particularly articulate teacher that was able to express his views and intentions clearly with respect to school science inquiry. Moreover, according to Keys and Bryan (2001), the painting of portraits of inquiry practices in a variety of diverse settings is needed. The local culture of a classroom with low-achieving students is therefore of interest, as it plays a significant role in the teacher's interpretation of inquiry practice.

The authors of the present paper have both been working as science teachers at the upper secondary level and are now working with science teacher education. Our experiences have given us an understanding of the important role of the teacher in improving school science. Narratives and quotes representing the teacher's story were shared with the teacher in order for him to check their intentionality. He supported our representation, as well as made some elaborations and clarifications that were taken into account.

Data Collection

Data were collected from December 2007 to May 2010. It included four in-depth semi-structured interviews with the teacher (eight hours total) as primary sources. The secondary sources were classroom observations, informal conversations and site documents from the open inquiry project. The interviews were performed by the first author. Data from the teacher interviews were triangulated with reference to classroom observations and site documents (Erickson 2012). Since we were in the field for a three year period, the tendency for the teacher and the students to exhibit contrived behaviours for the benefit of the researchers was minimized. In addition, we were able to consider whether a given statement was typical or atypical, increasing the study's internal validity. In addition, data were reviewed more holistically to provide a rich description of the context of the case (Derry et al. 2010).

Data Analysis

To analyse our case we have used an interpretive design that was derived from (Erickson 2012, 1986) to focus on "the immediate and local meanings of actions as defined from the actors' point of view" (Erickson 1986, p.119). The analysis followed an iterative process of reviewing evidence with an assertion in mind; subsequently, the assertion was revised in light of evidence, etc. (Erickson 2012). Firstly, we framed some working assertions concerning the teacher's beliefs and his practice of scientific inquiry that derived from classroom observations and informal conversations. These assertions were also informed by relevant literature familiar to the researchers. The assertions provided foci for semi-structured interviews and new classroom observations. Secondly, we transcribed all semi-structured interviews and performed an open coding using the software ATLAS.ti for qualitative analysis, searching the data for conceptual patterns that might confirm or disconfirm the working assertions (Erickson 2012). Discrepant instances were scrutinized carefully, as stressed by Erickson, and the working assertions were modified. Thirdly, we performed an analysis where the first step was the clustering of codes for the modified working assertions. Then, we made mind-maps, using the software www.text2mindmap.com, as a visual thinking tool to structure and explore the relationships between concepts related to each of the assertions. Finally, we found three emerging dimensions of the teacher's beliefs concerning NOS and the situated practice of open inquiry: (1) open inquiry as a way to motivate students and oppose rote learning, (2) nature as a source of knowledge by individual observation, and (3) scientific inquiry as a simple step-by-step method.

We use narratives connected to each of the three dimensions to convey the belief that was implicit in the stories of the teacher. To emphasize the patterns in his beliefs, we will complement the narratives by using excerpts from interviews with the teacher. We will also present discrepant statements concerning his beliefs. To summarize the teacher's beliefs, we made a cognitive map (Miles and Huberman 1994) to make explicit the teacher's beliefs as revealed through the narratives and to make visible the relationships between his beliefs (Figure 1).

Background Context of the 12-Week Open Inquiry Project

The context of the case study is a Norwegian upper secondary school located nearby the capital. It has mainly vocational education programmes, but offers a small section with programmes for general studies. According to the teachers at the school, being consistent with our impressions from three years field work, many of the students are not motivated for schoolwork in general, and the school struggles with a very high dropout rate. The science teacher has a master's degree in science and twelve year of experience as a science teacher at upper secondary schools. His students in the present case did not express any special interest in science, and many had a history of defeats relating to the more academic subjects at the school. It was without a doubt a challenging task for Amir to create interest for science in the student group. To meet some of those challenges, he had developed and implemented an open inquiry project, named "the scientific method", for ten years in his science classes.

The overall goals, formulated by the teacher, were for the students to learn the scientific method by studying a natural phenomenon and to stimulate their creativity, curiosity and motivation for science. The school laboratory was well equipped, including data loggers with multiple sensors. Amir introduced the open inquiry project by presenting what he called the "steps of the scientific method". Then, the students worked independently in groups of 3-5 persons whilst being guided by the teacher. Their work followed roughly the phases: developing ideas, formulating research question and making a research design, experimenting and discussing, presenting of posters and writing of a report. The students' choices of research problems were often close to their interests or daily life, e.g.: How do the emissions of CO2 change in cars produced in the period from 1980 and 2007? Is the quality of bottled water better than the tap water at the school?

Results

The following three dimensions were found to account for Amir's beliefs: (1) open inquiry as a way to motivate students and oppose rote learning, (2) nature as source of knowledge by individual observation and (3) scientific inquiry as a simple step-by-step method. We use narratives and excerpts from interviews with Amir, connected to each of the three dimensions, to convey the belief that was implicit in the teacher's stories.

Open Inquiry as a Way to Motivate Students and Oppose Rote Learning

The following narrative reveals how Amir perceives science is taught in Norwegian schools, and moreover why he provides his students with the opportunity to do open inquiry

> Science education in our school system is mostly about rote learning and repeating facts. The teachers depend very much on the textbook and acts like a newscaster. The students know what to learn and they reproduce it on tests. They follow the rules because it is easy and secures good grades. The problem with this way of learning is that it puts a lid on students' natural curiosity and creativity, and the students' basic relationship to science is not altered. It is difficult for a teacher to discover the students' potential during teacher-directed activities. Open inquiry gives me a chance to discover, map and educate the 'little scientist' that is found in the students, and it gives students a chance to blossom in science education. I have faith in the students, and I want to be their co-researcher and discover a phenomenon of their interest together with them. I do not force the students, I place myself shoulder-to-shoulder with them and we learn things together. I have experienced that students become more self-confident in school science through working with open inquiry. For instance, at oral examination, they show better reasoning abilities than other students do. In addition, they reveal a more balanced view on how knowledge is built in science. I believe it is caused by their direct involvement in the processes of scientific inquiry.

Amir reveals a concern related to school science as focusing on memorizing facts. In his opinion, this way of teaching alienates the students' relationship with nature and science, "Science has become news reading from the teacher that has a monopoly and students are just to be quiet, listen and make notes". As a contrast to this, he highlights the open inquiry project as a chance for students to engage personally in a phenomenon of their own interest. The following narrative reveals that his own experiences as a child seem to be important for his epistemological belief and a driving force for how he frames the open inquiry project.

> I have a great interest in science. It started when I was a child. I had a small notebook, which I named the "book of everything", where I made notes of observations and other interesting things, and I tried to set up possible explanations. I did not have a clue about hypothesis or observations, but I was just interested. I actually did a lot of experimenting as well with simple means. For me, the open inquiry project is first and foremost about upbringing and education, it gives students a chance to blossom by letting them do research on something of their own interest. It motivates me as well. My idea is to give the project as a gift to the students.

Amir's personal experience as a "little scientist" seems to be of importance for his teaching practice. He wants his students to experience that science is relevant and meaningful. They have experienced failure in academic subjects at school, and the open inquiry may represent a path for them into the world of science. It becomes clear that Amir sees open inquiry as an alternative form of teaching and learning that can create interest for science. Moreover, it motivates him in his work as a teacher.

Nature as Source of Knowledge by Individual Observation

The following narrative reveals Amir's positive emotions regarding nature, and how he believes science is for all.

> I see nature as holy. It provides pleasure and wonder. Nature is a source of knowledge, and it is essential for us. In my opinion, natural phenomena are everything that exists and happens in nature. It can be everything from ice crystals to cancer cells. Scientific inquiry gives us the possibility to study how things are connected in nature. We need to understand humans' relationship to nature, how we are influenced by nature and how we can influence it. Nature is a reference for everyone; no one has actual authority. So, we do not have problems with authorities that prevent creativity and restrain growth. I believe science is for all. It is democratic and gives freedom and possibilities.

The narrative reflects the teacher’s positive emotions relating to nature in his use of words such as “pleasure” and “wonder”. He believes that nature is the only true authority and that this makes science democratic; as expressed by him; “everyone is on equal footing”. Access to nature opposes a repressive school science culture, and this represents force in Amir’s beliefs. The framing of the school project reflects his thinking in the way that it encourages the students to connect with natural phenomena more than to authoritative documents. The following narrative reveals how Amir emphasizes that we relate to nature through observations.

> I would like the students to experience joy in relation with nature and science. They will observe a natural phenomenon that they are interested in, and they use logic and creativity to build a bridge between themselves and nature. The students will start with clean sheets. Our senses are the first approach towards a natural phenomenon; it can be described by using an analogue, a radio transmitter, in the way it plays a role in the reaction and signals that emerge. In my opinion, observation is an ability that can be trained, and I find that it is meditational and brings pleasure. When the students observe and use tools in order to explore their hypothesis. I can see that they enjoy it, and that they soon take ownership for what they are doing.

The narrative reflects Amir’s belief in observations providing an opportunity for the students to actively involve themselves in the inquiry process, and thus create positive experiences towards science. However, the following excerpt from an interview with Amir reveals what seems to be a positivistic position regarding the role of observations in scientific inquiry.

> I am going to draw parallels from the medieval considerations of true and false, and science in its nature is such that no one really has the authority, if I am poor or rich (...) from Africa or Japan. If I have found that water boils at 100 degrees at sea level, it does not matter whom we are. We are just basing it on the experiment, at a very objective level; therefore, in this field, all human are set equal. (Amir, December 2007)

Amir is framing the project as individual thinking and learning, where students connect with a phenomenon using their own senses and logic. This view correlates with a positivist view on science, not taking into account the significance of argumentation in the scientific community as social norms in institutionalized practices.

Scientific Inquiry as a Simple Step-by-step Method

The following narrative reveals Amir's beliefs in scientific inquiry designed as a simple step-by-step method in classrooms with low-achieving students.

> Scientific inquiry is very complex, and the students will only get a small taste of it. I simplify it by presenting it as a step-by-step method, like a thread you can follow. These students will lose interest and motivation if you push them too much. You need to be careful not to present too much theory and conceptual framework for what they are going to do. If you do this, they will retreat. Most of them have a history of defeats in the academic subjects. In this project, we have a focus on the experimental side of science. They start the inquiry on a phenomenon by using their logic, creativity and tools to see how things are connected. During the inquiry, the students will experience that the method is more complicated than first expected, and they often need to make new hypotheses and designs when the first one fails. They learn to be critical towards their own work, they understand that there are many things that they did not have time to explore, they reflect critically on their findings and they do not think they have "found the truth".

The narrative reveals that Amir frames the open inquiry as a simple step-by-step method to remove complexity for his students' with low performance, and thus support their confidence in that they can master the task. During the process of inquiry the students will experience some of the complexity themselves. His view is further elaborated in the following quote from an interview.

> You can teach them that indeed you are sitting with a blank sheet of paper. You have a phenomenon and a tool, and then, you have something that all the time can bring you further in the learning process. They see that it is actually almost a recipe. (Amir, May 2010)

In this context, the conceptual frameworks and structures implemented to support an inquiry process may be seen by Amir as "doing school" and stand in contrast to the learning process of the students from a "blank sheet of paper". In the following quote from an interview, his epistemological view becomes more explicit.

> I have told them (the students) (...) that the scientific method is actually an ideal recipe. (...). Many great scientists do not necessarily follow this method. Many of them have a very critical attitude to the method; the whole logic of the scientific method is not something on which they have agreed. (...) It is not necessarily the only method. (Amir, December 2007)

His espoused belief in a simplified scientific method for the school context is discrepant to his more sophisticated view on authentic scientific inquiry; suggesting that he distinguishes between the school version and authentic versions. This point also becomes clearer in the following quote he reflected the lack of theory in the students' projects.

> You know, the expectation that they should be able to connect a proper theory, in a professional way, I believe it is unrealistic (…). I think you need more maturity to be able to bring in the correct theory to describe what you do. (Amir, May 2010)

In a note written after Amir had read our representation of his beliefs concerning NOS and scientific inquiry in the situated school context, he elaborated the following point of view.

> In a way, students 'realize' themselves by working with 'the scientific method', that they actually construct knowledge about the natural phenomenon. Thus, they look at scientific knowledge as something that is formed by their personal/psychological/social norms in addition to the natural phenomenon itself and experiments. (Amir, June 2012)

The statement reflects that he believes that students will implicitly, by engaging in scientific inquiry, appreciate the social and personal nature of science. This reveals a somewhat more nuanced view on nature as a source of knowledge. Thus, Amir's framing of scientific inquiry as an individual approach represents scope and force for him as a means to empower students by erasing boundaries between them and science. To bring in the social community as a central part of the nature of science may stand in opposition to the teacher's idea of connecting students with a phenomenon without too much complexity that could disturb the students' personal experiences. The narratives and quotes presented represent a broader ecology of Amir's beliefs concerning NOS and scientific inquiry in school. We have summarized the main findings in a conceptual map (Figure 1).

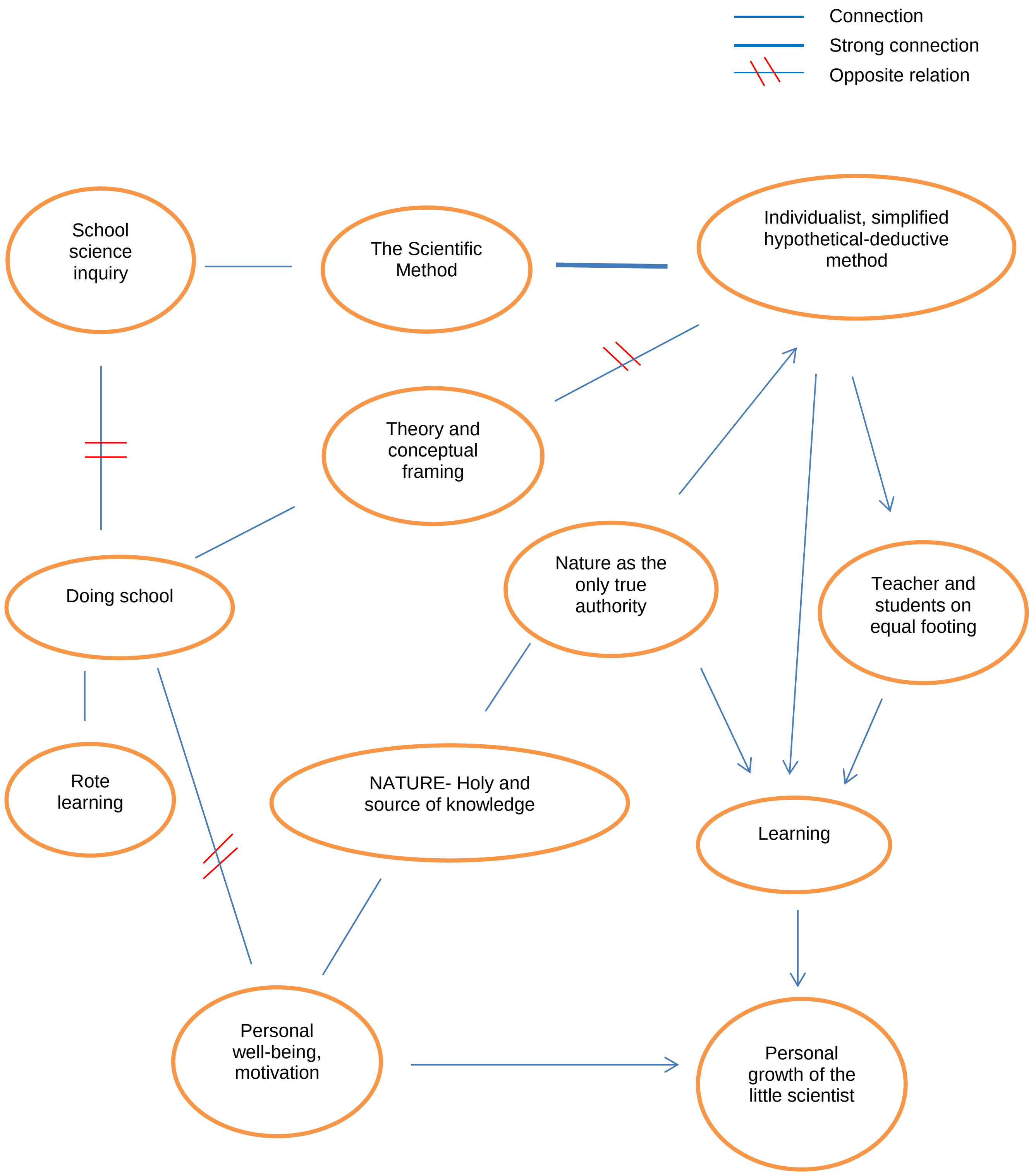


Figure 1. Conceptual map of Amir’s beliefs concerning school science inquiry

Discussion

It is well known that teachers may hold beliefs about NOS that are at odds with tenets found in the research literature, and that although these beliefs are important they may not be consistent with what is observed in teachers' practices. Our contribution is to show in our analysis of an experienced science teacher that belief about NOS, even if problematic in light of science educational research, gain scope and force by their connections to other beliefs structures also important to schooling. In the following, we will discuss the experienced science teacher's beliefs concerning NOS and practice of scientific inquiry, as well as further discuss why these beliefs represent scope and force for the teacher in a situated context with low-achieving students. Finally, some implications for science teacher education will be suggested.

The current study has shown that Amir combines elements from "traditional inductivist views" (Hodson 1996) with a simplified hypothetical-deductive method (Duschl and Grandy 2008). The deductive aspect opens for a creative side of theory formation, which is an important part of the teacher's goal of fostering the "little scientist". Students can inquire about just anything using the scientific method; nature will correct their understanding if it is not correct. However, as there is little emphasis on theoretical understanding, the inductivist part becomes most important; students learn from inferences based on observations. The problematic tenet of inductivism is that theory-independent evidence is obtainable.

However, what give Amir's beliefs scope and force are not formal epistemological principles from the philosophy of science, but his educational agenda, which is his ambition for the personal growth of his students. By the scientific method students are provided a tool connecting them with natural phenomena. They can learn from nature by this method driven by their curiosity. Previous failures as learners can be left behind and uninteresting and passive rote learning are replaced by active inquiry. In this sense, the scientific method "rescues" students from what Amir's sees as a harmful school culture, the norms of "doing schooling" (Schleppegrell 2002).

This implies an empowerment of the individual over tradition that has a historical parallel in the history of science. According to Shapin (1996), what the 17th century natural philosophers considered their most profound task was to identify methods that could ensure reliable knowledge. Such knowledge would need to be strong enough to refute the authority of classical literature. A cornerstone in this struggle was to seek knowledge in 'the book of nature' instead of the authorities of ancient tradition (most notably, Aristotle). This refutation of classical authority has been interpreted by Shapin (ibid.) as a part of reactions against a natural philosophy that had proved itself helpless when confronted with practical, everyday problems and was seriously hampered by academic quarrels and petty rivalry. It was necessary to tune down the social dimension and address nature more directly, seeking “the method”. However, the devaluation of both the social dimension and the authority of the classics were implemented in the sense that knowledge was now to be sought inductively from conscientious documentation of singular experience (Knain and Flyum 2003). This empowerment of individual experience of nature over classical authority parallels Amir’s ambition to empower his students to prevail over a repressive school culture by the scientific method. This also implies profound changes in his role as teacher. With the scientific method in hand, he can step out of a traditional teacher role and become a co-investigator and motivator in the joint adventure of exploring natural phenomena. In this sense, Amir too, not only his students, steps out of a repressive school culture. Thus, his simplified scientific method that may be criticized on philosophical and social grounds is motivated by pedagogical concerns and driven by care for his students.

The development of a science curriculum must be looked upon in a contextual way, taking into account the situated school contexts and the teachers’ knowledge and beliefs (Barnett and Hodson 2001). Thus, the pedagogical considerations espoused by Amir must be understood in situated practice with students that have low sense of mastery in science, finding it alienating and not relevant in their lives. Open inquiry may provide opportunities for these students to engage in activities to which they are committed (Wells 1999). Moreover, real issues, where students do not know the answer, could be a way to oppose the impression that science is not related to everyday life (Hodson 2009). Furthermore, it makes sense for a teacher not to present more of the same traditional teaching that made these students feel powerless. In the case of Amir, he focuses on the affective value of the individual students’ pleasures when they explore a natural phenomenon of own interest. This can be well understood in light of Amir’s own positive experiences as “a little scientist”. His role as a teacher was to create a safe learning environment and to work closely with the students, discovering and enjoying their “research” together with them. This teacher role represented a strong force in Amir’s motivation of being a teacher.

Implications for Science Teacher Education and Professional Development

The present study reveals how a teacher’s personal beliefs can be construed as a network of context-dependent considerations that are vital components in framing a practice of scientific inquiry in school. Problematic and sound beliefs, from the perspective of educational research, may coexist and bring flexibility to the beliefs structures. This may be a reason why research on teachers’ professional growth reveals that the personal beliefs and images the teacher students bring to teacher education normally remain inflexible (Kagan 1992). According to the Kagan, students tend to use educational coursework to confirm rather than confront and correct pre-existing beliefs.

We follow Hattingh and De Kock (2008) and Samuel (2003) in that once teacher students are able to identify and reveal the forces that impact on and drive their actions and reactions, they are able to critique them, to alter them and to modify their influence over them. However, we emphasize that part of this enterprise should be to become aware of the strengths to build further development on as well. Thus, we suggest that in order for teacher students to prepare for and develop their practice of inquiry in school, they need to reflect on personal experiences and emotions towards scientific inquiry, as well as how they may affect their situated practice. This emphasises the value of teacher students spending time on a productive inward journey in the developmental process of their professional identity (Beijaard et al. 2004; Nias 1996). Teacher students may then identify the relevant aspects of their beliefs and concerns that need to be considered for a change in teaching practice of scientific inquiry to occur. The reason why simplified versions of scientific inquiry continue to rule in school science may be that in addition to beliefs concerning NOS, the strong educational and personal sides to teachers' framing of their practice is not considered a part of both the problem and the solution.

Acknowledgment

This material is based upon work supported by the Research Council of Norway, as part of the project "students as researchers", grant number: 423301-NFR.

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Scaffolding open inquiry: How a teacher provides students with structure and space

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Abstract

The present case study examines a teacher's scaffolding strategies supporting his students during a twelve-week open inquiry project at an upper secondary school. Data include video recordings and site documents from the project. We use interaction analysis to identify how he provides the students with *structure* and *space* in the different phases of open inquiry as well as how it constitutes the students' learning experiences. The study reveals that the teacher scaffolded this open inquiry in two opposing ways; he created *space* for the students to make their own experiences and ideas, which eventually set up the need for more directed scaffolding to discuss the challenges students experienced, and directing students' attention and ideas in certain directions in phases with *structure.* We suggest that there exist a necessary tension and interplay between structure and space, creating what can be seen as a driving force providing both exploration and direction for open inquiry. Moreover, we propose that the notion of 'structure and space' can work as a thinking tool to promote teachers' competence on how to scaffold more authentic versions of scientific inquiry in schools.

Introduction

Science education reforms all over the world advocate a view of learning science that emphasises inquiry (e.g. European Commission, 2007; Norwegian Ministry of Education, 2006; NRC, 2000). In the classroom, the term 'inquiry' can be understood with two different emphases: the experiments and activities that facilitate the students' learning of established sciences and the scientific thinking and practices in which students engage when they model professional scientists (Anderson, 2002; Asay & Orgill, 2010) – which is in focus in the classroom studied here. Specifically, open inquiry has been proposed as a means to enhance more authentic scientific inquiry (Duschl & Grandy, 2008; Roth, 2012) and promote active and autonomous learning (Hodson, 2009). However, change in the sciences in schools depends upon how teachers conceptualise inquiry and how it is translated into classroom practice. We are following Blanchard and her colleagues (2010) in that we need to understand how the teacher's actions influence the nature of students' inquiry process.

In this case study, we use interaction analysis to understand how an experienced upper-secondary science teacher's scaffolding strategies impact the nature of an open-inquiry practice and students' learning experiences. It is proposed that, in open inquiry, the teacher's role change from an instruction-oriented role to a more guidance-oriented role (Crawford, 2000). An important notion concerning the teacher's role is raised by Hodson (2009) when he proposes that: 'Too much guidance can interfere with students' thought processes, act to frustrate problem solving and lead to premature closure; too little guidance can leave students unable to make satisfactory progress and lead to feelings of frustrations, and even alienation' (p. 213). Thus, there must be some kind of balance between offering the students *structure*, which scaffolds the essential features of scientific inquiry (Asay & Orgill, 2010; Windschitl, Thompson & Braaten, 2008), and *space* to express their thoughts, ideas and tentative understandings (Wells, 1999). van der Valk and de Jong (2009) suggest that teachers need to know how to guide students' open inquiry projects, 'especially the ability to know when and how to give students a well-balanced combination of "structure" for open-inquiry learning and sufficient "space" for that' (p. 829). The authors provide examples of several scaffolding tools, but they do not provide empirical data on how these tools were used by the teachers and what the consequences were for the students' learning process. Furthermore, they do not provide descriptions of what the term 'space' might constitute in open inquiry. Thus, more detailed descriptions from situated inquiry practices revealing how teachers combine structure and space as well as the consequences for the inquiry process are of interest. The research focus for the study, consequently, is how a teacher scaffolds the students' learning of the essential features of scientific inquiry and the development of autonomy during open inquiry.

The questions guiding this case study are:

1. What were the teacher's scaffolding strategies in the different phases of open inquiry?
2. How did the teacher's scaffolding, combining structure and space, constitute the students' inquiry process?

Theoretical framework

Open inquiry in school science as modelling professional science

Open inquiry is often described as a student-centred approach where the students are supposed to learn about the essential features of scientific inquiry through their own experiences (Asay & Orgill, 2010). According to the National Research Council (NRC, 2000), the five essential features for inquiry in school are: (a) the learner engages in scientifically oriented questions; (b) the learner gives priority to evidence in responding to questions; (c) the learner formulates explanations from evidence; (d) the learner connects explanations to scientific knowledge; and (e) the learner communicates and justifies explanations (p. 29). Open or full inquiry is supposed to cover all five features, and it has been suggested to replace the recipe-type of practical work in school because it is more closely related to scientific activity and reasoning (Duschl & Grandy, 2008; Roth, 2012). Moreover, open inquiry is advanced as a means to provide students with the possibility to achieve some intellectual and creative independence in taking responsibility for developing ideas and planning, executing and reporting their own inquiries (Hodson, 2009; Zion & Slezak, 2005). Open inquiry is also promoted as an opportunity for students to engage in activities to which they are committed (Hodson, 2009; Wells, 1999; Zion et al., 2004).

However, there are tensions between the purpose of open inquiry and the practice actually found in schools. Research reveals that open inquiry often portrays naïve versions of scientific inquiry and does not model professional science (Windschitl, 2004). For example, new technologies and new scientific theories have modified the nature of scientific observation from a practice dominated by sense perception to a theory-driven practice (Duschl, Deaák, Ellenbogen & Holton, 1999). Nevertheless, this is not reflected in school scientific inquiry, where 'observations' are mostly directed by the teacher or guided by students' interests. It is seldom acknowledged as being influenced by prior knowledge, theory or models (Duschl & Grandy, 2008; Windschitl, 2004). The questions arising from students' interests are rarely informed by their understanding of a phenomenon, and this is problematic since it reinforces a naïve presumption that hypotheses are guesses about an outcome (Carey, Evans, Honda, Jay & Unger, 1989; Gyllenpalm, Wickman & Holmgren, 2010). Furthermore, the way inquiry is often presented in school as 'testing of hypotheses' following a linear process named The Scientific Method, is problematic since scientific inquiry does not embody a step-by-step method based on an experimental design (Lederman & Lederman, 2012; Windschitl et al., 2008). Neither does it represent a single universal scientific method, but rather, many different approaches depending on the subfield of science (Giere, Bickle & Mauldin, 1997).

The process of open inquiry is complex, and the problems to be dealt with are ill-structured. This puts high demands on the students and the teacher. The students are supposed to achieve some sort of intellectual independence, using knowledge in creative ways for solving novel problems and building new understandings (Hodson, 2009). Therefore, the students need to learn how to fulfil a more autonomous role during the process of inquiry. Simultaneously, the teacher needs to ensure the students' understanding of the culturally and socially accepted views of what constitutes scientific inquiry (Wells, 1999). However, student-centred approaches have been accused of being unguided or minimally guided, making them less efficient than instructional approaches (Kirschner, Sweller & Clark, 2006). This critique has, among others, been encountered by Hmelo-Silver, Duncan and Chinn (2007), who have argued that successful inquiry-based learning and problem-based learning are characterised by extensive scaffolding. Moreover, Hmelo-Silver and her colleagues propose that the more important question is not 'Does it work'? Rather, we should ask under what circumstances does it work, what kind of valued practice is promoted and what kinds of support and scaffolding are needed for different students and learning goals. However, the literature also reports teachers' lack of experience and knowledge about how to facilitate inquiry-based learning, resulting in poor learning outcomes (e.g. Asay & Orgill, 2010). This brings us to the significant role the teacher plays in supporting the students' learning from open inquiry.

The teacher's role in scaffolding students' learning during open inquiry

The scaffolding metaphor originally described a tutorial process where 'an adult or "expert" helps somebody who is less adult or less expert' (Wood, Bruner & Ross, 1976, p. 89). In a school context, this can be a teacher adjusting the complexity of a learning task so the students can engage in activities that would be beyond their unassisted efforts (Bliss, Askew & Macrae, 1996). However, the notion of scaffolding has expanded to include tools, strategies and guides to support learning processes (Saye & Brush, 2001; Sherin, Reiser & Edelson, 2004). The form of scaffolding depends on the nature of the learning task, the particular students involved and the specific educational context. Furthermore, it changes over time. This means that, as the students gain experience with the task, support should be decreased (ibid.). Hmelo-Silver and her colleagues (2007) highlight the way in which scaffolding is used: to make disciplinary strategies explicit in students' interactions with the task and tools as well as the artifacts they create; to structure complex tasks or reduce cognitive load; and to provide expert guidance. Hodson (2009) suggests the following scaffolding strategies for inquiry learning: a) reducing the complexity of a task; b) sequencing a complex task into a series of simpler ones; c) making suggestions, asking questions and providing cues to enable students to focus on particular elements and clarify their understanding; and d) providing constructive feedback and support that enable students to diagnose their own problems and difficulties as well as build their self-confidence (p. 214). Wood and his colleagues (1976) also include the recruitment of interest in and adherence to the task as part of a scaffolding process.

Furthermore, scaffolding students in open inquiry involves a teacher's ability to know when and how to give students a well-balanced combination of *structure* and *space* (van der Valk & de Jong, 2009). However, the authors do not discuss explicitly what is meant by 'structure' and 'space', respectively. Searching research literature on open inquiry, there seems to be agreement that the students need *structure* in the form of scaffolding tools and teacher guidance to help them organise and direct their own projects (Crawford, 2000; Hodson, 2009; van der Valk & de Jong, 2009) and to learn essential features of scientific inquiry and relevant conceptual understanding (Asay & Orgill, 2010; Windschitl et al., 2008). Moreover, it is vital for a teacher to create *space* during open inquiry for the students to follow their particular interests (Hodson, 2009; Wells, 1999) and to experience situations requiring creativity and critical thinking and reasoning skills (Hodson, 2009; Zion & Slezak, 2005).

The literature reviewed here advanced several scaffolding strategies to support the different purposes and aspects of inquiry in school. Inspired by the literature, we have identified three main scaffolding strategies that support the research focus of the present case study. These strategies are as follows:

(1) scaffolding that makes the essential features of scientific inquiry explicit;

(2) scaffolding that structures complex tasks or reduces cognitive load; and

(3) scaffolding that facilitates phases with space for student autonomy.

Methods

The present case is an in-depth study of an experienced science teacher and his day-to-day interaction with students during an open-inquiry project. The approach provides an opportunity to study the teacher and a group of students to identify the teacher's scaffolding and how it influences the nature of the students' inquiry process. We follow Flyvbjerg (2011) in that single-case studies can be of great importance since they produce rich, context-dependent knowledge, thus increasing our understanding of a phenomenon. Furthermore, teachers provide important insight into the classroom that is unavailable from any other resources (Keys & Bryan, 2001). For this reason, we have chosen to follow an experienced and particularly articulate science teacher who was able to clearly express his views and intentions with open inquiry. Moreover, the teacher and his students were willing to open up their classroom for several months and share their experiences and thoughts.

Sources of data

The first author observed the whole class of 24 upper-secondary students and their science teacher from January to April 2010 during their science lessons. To get rich descriptions of the inquiry practice and data relevant for the research question, the main focus was on interactions between the teacher and one particular student group. This student group was selected on the following bases: it was a heterogeneous group when it came to interest in science, the students were willing to express themselves in front of the camera, and they had fewer absences from school than some of the other students in the class. The teacher, Amir, has developed and implemented the open-inquiry project for ten years in his science classes. Amir holds a master's degree in science, and he has twelve years of experience as a science teacher in upper-secondary schools. The science teacher and the first author were familiar to each other from two previous years of collaboration at the school; this was valuable because it provided a situated understanding of the important role of a teacher in school scientific inquiry.

Data included the primary sources of video recordings from the whole-class setting and the chosen student group and site documents from the project. The secondary sources were semi-structured interviews with the teacher, informal conversations and field notes. Data were collected during a six-month period fully covering the inquiry project studied. The analysis was performed by the first author and also read and commented on by the second author familiar to the project. Since the first author was in the field for a prolonged period of time, the tendency for the teacher and students to exhibit contrived behaviours for the benefit of the researcher was minimised. In addition, the author was able to see whether a given behaviour or statements were typical or atypical and thus increase the study's internal validity. In addition, data were reviewed more holistically to give a rich description of the context of the case (Derry et al., 2010).

Analysis of data

To analyse the case, we used an interpretive method (Erickson, 2012), which followed a hermeneutic cycle. *First,* some working assertions were made about the teacher's role in scaffolding the students' inquiry projects, inspired by previous years observing the open-inquiry project and relevant research literature. The assertions provided foci for new classroom observations. S*econd,* the data was searched for information that might confirm or disconfirm the working assertions (ibid.). Moreover, the transcripts of the video recordings and the site documents from the classroom were coded and analysed using the software ATLAS.ti to facilitate the keeping track of codes and emergent assertions. Data from the classroom were coded for the teacher's scaffolding within the three main strategies identified above: (1) scaffolding that makes the essential features of scientific inquiry explicit, (2) scaffolding that structures complex tasks or reduces cognitive load and (3) scaffolding that facilitates phases with space for student autonomy. *Third*, a thematic analysis was done through the clustering of codes from the transcribed material to define the framework of the project and the teacher's scaffolding strategies (Table 1). In the *fourth* step, interaction analysis was used to enable the formulation of *emerging issues* (Jordan & Henderson, 1995), identifying how the teacher's scaffolding of his students, providing them with *structure* and *space*, constituted their inquiry process. The interaction analysis was inspired by Högström, Ottander and Benckert (2010) and their analysis of teacher-student and student-student interaction during practical work. Emerging issues were found by identifying words and concepts that were continuously repeated, long versus short discussions between the participants and situations where the teacher or the students expressed frustration or excitement. When several instances of an issue emerged across situations, they provided a demonstration of the type of issue identified as robust.

The context of the open inquiry project

The context of the case study is a Norwegian upper-secondary school located near the capital. It has mainly vocational education programmes, but offers a small section with programmes for general studies. According to Amir, most students in the class were not motivated for science, and they typically displayed a shallow understanding of scientific concepts and processes. This description is consistent with our impressions during the project. In addition, the school struggled with a very high percentage of dropouts. It was, without doubt, a challenging task for the teacher to create an interest in science. Amir is an experienced science teacher, and he was sensitive to the different challenges these students presented, concerning science as a subject and social issues.

The open inquiry project lasted for 12 weeks, and the students got to spend approximately two lessons a week (45 minutes each lesson) on the project. The teacher had formulated the following goals for the project: The students should learn The Scientific Method; build knowledge and stimulate their curiosity by studying a natural phenomenon, and increase their ICT competences in the natural sciences by using digital sensors in field work and digital publications. In addition, the teacher formulated the goal of creating an interest in science by giving the students opportunities to be in charge of their role as natural scientists. The formal curricular goal relevant to the project was, according to Amir, 'the budding researcher', an important area in the Norwegian national science curriculum focusing on scientific inquiry (Norwegian Ministry of Education and Research, 2006). The students collaborated in groups consisting of three to five persons. The students' inquiry projects were very diverse, for example: Is bottled water healthier than tap water? Or, what is the connection between increased CO_2 emissions and plants' ability to produce oxygen? The group we chose to follow in this case study consisted of three girls: Marie and Martha, who were not especially interested in science, and Sofie, who expressed an interest in science and showed more motivation for the project. The group decided to study the effect of pollution on hair quality, a phenomenon presumably close to their daily life and interests. This student group is referred to as ‘the hair group’.

Results

The results of the analysis are presented in two parts: The first reveals the teacher’s scaffolding strategies in different phases of the open inquiry (Table 1), and the second part shows the result of the interaction analysis, revealing two main, emerging issues concerning how the teacher’s alternation between providing *structure* and *space* constituted the students’ inquiry process.

Phase of the inquiry project	***Introduction*** (2 h)	***Design and planning*** (4 h)	***Performance and reflection*** (10 h)	***Presentation*** (3 h)
Activities	Introduction by the teacher to the project and The Scientific Method	Students worked with ideas and formulated the research question, hypotheses and a research design	Students did experiments and collected data, and they discussed the results	Students presented their results in the form of a poster, and they handed in a written report
(1) scaffolding that makes the essential features of scientific inquiry explicit	Modelling The Scientific Method using a simple example about worms. Asking questions and providing cues Providing examples from previous student projects	Verbally guiding the individual student groups concerning ideas and measuring methods Research meeting 1*	Verbally guiding student groups concerning procedural issues Data loggers and software to collect and record data as well as make graphs and tables Research meeting 2*	Verbal guiding with students’ groups Poster session
(2) scaffolding that structures complex tasks or reduces cognitive load	PowerPoint presenting The Scientific Method as a step-by-step method Show posters from previous projects	Whole-class instructions to guide the students’ progress: as a road sign Learning platform containing: • template for the tasks following The Scientific Method • template for log • room for feedback from the teacher • links to literature • timetable • assessment criteria	Whole-class instructions guiding the students’ progress: as a road sign Learning platform resources (same scaffolds as in the planning phase)	Whole-class instructions guiding the students concerning the poster exhibition Template for the posters Posters from previous years’ projects
(3) scaffolding phases with space for student autonomy	Intriguing examples for recruitment to the project Legitimise creativity and independence	Learning platform resources Research meeting 1* Questions that open up students’ ideas and thought processes Encourage creative solutions	Learning platform resources Research meeting 2* Questions that open up students’ ideas and thought processes Encourage independence	Template for poster Encourage creative solutions regarding the poster exhibition

Table 1: The teacher’s scaffolding strategies providing structure (1 and 2) and space (3) in the different phases of the inquiry project. *Research meetings 1 and 2 modelled professional science in the way that the students were supposed to present ideas and preliminary findings for each other and provide feedback.

Identifying how the teacher's scaffolding constituted the students' inquiry
From the interaction analysis, two main, emerging issues were identified revealing how the teacher alternated between providing the students with structure and space and how it constituted their learning experience during the four phases of the inquiry project.

Using The Scientific Method to structure open inquiry and create space for ideas
During the introduction and planning phases, the teacher continuously repeated The Scientific Method both to model scientific inquiry and as a step-by-step method scaffolding the inquiry project. In addition, he focused, with enthusiastic verbal guidance, on the possibilities open inquiry provided the students to explore a natural phenomenon in which they were interested. The emerging issue reveals that the teacher used The Scientific Method to structure open inquiry and create space for the students' own ideas. The emerging issue is illustrated by the following examples that emerged across situations.

Amir introduced the project by presenting learning goals and the relevant formal curriculum to structure and narrow down the focus of the open inquiry. Moreover, he used a PowerPoint with pictures, texts and drawings to explain the so-called steps of The Scientific Method. Interactions were directed by Amir, using cues and asking simple questions in a whole-class setting. Figure 1 represents the teacher's PowerPoint slide summing up the inquiry process for the students.

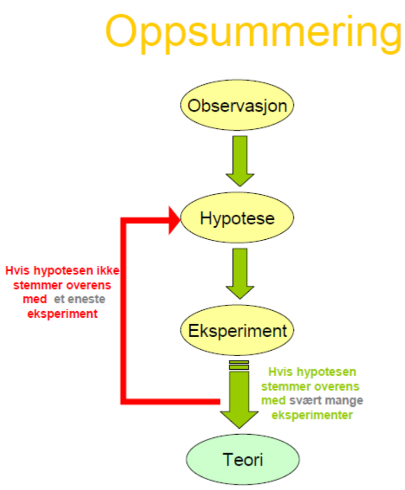

Figure 1. The teacher's representation of the main steps of The Scientific Method ("Observation → Hypothesis → Experiment → Theory'. Red arrow: 'If the hypothesis is not consistent with a single experiment')

The following words from Amir guiding his students emphasise his concern: 'Whether it be four steps or a hundred, this is the essence (of The Scientific Method)'. This four-step structure not only gave students an overview that was possible for them to remember and motivated them by making the process seem manageable, but it also narrowed the students' tasks by making some activities seem relevant and others irrelevant in different phases of the project. Thus, it put restrictions on the students' activities and provided a focus for their thinking, indicating that there was no 'space' for going outside these borders.

Moreover, Amir presented a site at the learning platform to scaffold the project, including a template for the inquiry process, a timetable and the assessment criteria. The content of the template is given in Figure 2.

Theme/problem	Write a short and precise title that shows what you are doing research on…
Observation/background	What have you observed, learned, or know about the phenomenon you want to study? Why did you choose your theme?
Hypothesis	A well-thought-through guess/assertion you state is the main cause of the phenomenon
Experiment	What are the experiments you want to perform to find out if your hypothesis is valid?
This week's log	Write at least, once a week, a short but precise report about what you have done/what has happened regarding the research problem. Important: each group member should choose her own colour for the text when writing a log or other things.
Literature/relevant theory	Here you can write/cut and paste theory you read/find during the process.
Questions	Here you can ask questions to me or other supervisors (professional problems and other practical things that concern your problem).
Comments from the teacher	Here there will be comments when necessary from all the students in the class and the teachers.

Figure 2. The template at the learning platform used to scaffold the students' inquiry projects

The students were supposed to fill in the template during the inquiry, and the teacher inserted feedback directly into the table. Thus, it worked as a guide for the students, focusing the students' work into presumably achievable pieces. Moreover, the template included the main steps of The Scientific Method (Figure 1). In that sense, Amir used The Scientific Method both as a *method of scientific inquiry* and as a *method for scaffolding* the students' inquiry projects, possibly reinforcing the image of scientific inquiry as a step-by-step procedure to follow.
The following excerpt reveals what the hair group wrote in their template about the observation/background for their inquiry project.

> We are concerned about hair and how it looks, that it's healthy and fresh and how we style it. (…) We did not know anything in particular about research on hair previously, but we thought this could be interesting. It took some time before we found out just what we would like to discover about hair. Finally, we decided that we wanted to investigate if smoking over time damages your hair. There are many kids who smoke today, and they

> are very concerned about their hair, so we thought it would be interesting to investigate this.

The students chose a phenomenon that was close to their daily life and intriguing for them to explore. Amir created a space for the students to use their creativity to find their own ideas within the framework of The Scientific Method, thus facilitating the students' thinking about researchable problems. The following excerpt illustrates how Amir used verbal guidance in the planning phase to encourage the students to follow their interests.

> Amir: Did you come any further with your research problem and hypotheses?
>
> Sofie: We've found some things…the research problem is the pollution of hair, and we've found some subcategories like cigarette smoke, street pollution, bonfires, dirty hair, clean hair etc.
>
> Amir: Mm, yes. Actually, it is fascinating; I find every case exciting to look at. This is the first and last opportunity you have in upper secondary school to do something from scratch, so I hope and expect that you'll participate fully. (…). Throw yourself wholeheartedly into the problem. I think you'll get many good findings.

The excerpt reveals that Amir's concern was approving the students' ideas; enlisting the students' interest in and adherence to the project. Thus, he was creating a space by legitimising creativity and independence within the framework of The Scientific Method. In sum, during the phases of introduction and planning, Amir chose to focus on The Scientific Method as a model for scientific inquiry as well as a scaffolding strategy in the form of a template framing the students' work and dialogues. The students were asked to follow and fill out the template, providing structure for the inquiry process and simultaneously allowing space to introduce their own ideas within the constraints of the structuring template.

Thus, the duplicity of the template somewhat meets the tension between Amir's concern of opening up for students' interests and thought processes relating to a natural phenomenon and his awareness of the need to provide structure to enable students to fulfil the inquiry and develop certain insights. Moreover, having narrowed the students' freedom through the demands of the template and the model of the scientific inquiry, the teacher could provide space for students' ideas while still keeping the work relevant for the identified learning goals.

Providing space to experience the complexity of inquiry and readiness for guidance

In the performance and reflection phase, when the students worked independently in groups, collecting data and struggling to make sense of it, they experienced that The Scientific Method was more complex than they first anticipated from the teacher's initial guidance. Moreover, the analysis reveals that the experiences made in periods of space were important for the students' readiness for guidance through scaffolding structures like ‘research meeting 2’ and the poster session.

During the performance phase, interactions between the teacher and the students changed in character towards real-time guidance, which was less frequent. The teacher encouraged the students to solve the tasks within the group, and student-student interactions were dominant. The hair group enjoyed using the equipment available at the school lab to test hair samples, measuring hair strength with a digital force meter, hair thickness with a digital calliper, the amount of ‘pollution’ on the hair using a turbidity meter, and a microscope to observe hair structure. However, the lack of proper research design made them explore several parameters without clear purpose, and their progress was slow. Nevertheless, the space did provide the students with some valuable experiences concerning the process of inquiry. The following excerpt illustrates how the hair group discovered an important methodological limitation that helped them to reduce the amount of hypotheses, control variables and finally make a design:

> Sofie: If we are going to include smokers, how are we going to study that? I think that, if we’re looking at Nina’s hair [smoker], I don’t believe it will be more polluted than … it has to be damaged in some [other] way. We can look for thickness, but then of course, people’s hair has different thickness from the start. We can check strength, but anyway, people’s hair can have different strengths [from the start]. It will be totally uninteresting since we won’t know if it’s the result of smoking. But what we can do is take samples from many people.
>
> Marie: You can smoke a cigarette in front of a person that doesn’t smoke.
>
> Sofie: But, do you know what we can do? …take a hair sample from someone that has never smoked and hair from several smokers and see if there’s a correlation.
>
> Martha: Yeah, we need to have more… [samples].
>
> Marie: Yeah, we need to cut down on the number of other hypotheses.
>
> Sofie: Then it will only be smokers or no smokers. …okay, we must reconsider the whole thing.

The excerpt reveals how the students were able to solve emerging problems together to find a research design that could take into account people’s different hair quality.

In the phase of performance and reflection, the students’ talk was largely about procedures and fair testing. The scaffolding structure ‘research meeting 2’ was implemented for the students to present their preliminary findings and suggest how their data could be interpreted to answer their research question and to get feedback on their work. The following excerpt from the research meeting illustrates how the hair group presented their findings.

> Martha: We haven’t made any connection between the results with data yet.
>
> Sofie: Theory...

> Martha: Or something, we have not…
>
> Sofie: We’ve found some theory that makes us believe that there is a connection between hair and whether you smoke or not. Then, there are the sources of error like the equipment (...) and if we have enough hair samples to actually see a connection, because all people have different hair thicknesses and so on (...). I think there is a correlation between smokers and their hair, but I'm not sure if we’ll be able to see this, because there are too many discrepancies and errors.

The students were able to reflect on important procedural issues that they had experienced themselves through the inquiry process. In ‘research meeting 2’, the peers were supposed to act as ‘critical friends’. In this case, their questions were about measuring uncertainties, thus reinforcing the focus on procedural issues.

In the lesson preceding the poster exhibition, the hair group was still collecting data. The deadline to finish the experiments conflicted with the time necessary to discuss the data. This conflicted with the teacher’s intentions regarding assessment criteria and ‘research meeting 2’, focusing more on understanding data within a theoretical framework. At the poster exhibition, Amir had arranged for external judges to assess the projects and select the winners of three prizes. The following excerpt is from a conversation between the hair group and Petter (judge), revealing how Martha reflected on the limitations of their study and what she had learned from it.

> Petter: So, there are other variables that interfere with the variables you were looking for. How many samples were needed then, do you think?
>
> Martha: Eh, we should probably have had up to a hundred for each of them ... to see ... we should at least have much more than the four we had. And we should have been much more careful so the people we took hair samples from washed their hair with the same shampoo and did it just before they gave us the hair samples and gave us information if they coloured it or used a hair straightener.
>
> Petter: Okay, so you could have planned in more detail the tests you did. (...) It seems that you have learned a lot about how difficult it can be to measure such things.
>
> Martha: Yeah, that's probably what we have learned the most of, how much you need to know and how hard it is to come up with concrete things.

In sum, the students were able to reflect critically on what went wrong and what they could have done differently concerning important procedural issues. The hair group’s own experiences with complexity provided a foundation for guided reflections in ‘research meeting 2’ and with the judge regarding some essential features of inquiry.

Thus, in the phase of performance and reflection, the emerging issue revealed that the teacher provided space for the students to create their own experiences. Moreover, he used these first-hand experiences as a valuable point of departure for guidance to support and make explicit important procedural features of scientific inquiry. This guidance narrowed the possible ways of interpreting and handling the problems experienced. It was followed by an open phase in which students tried to take advantage of comments in the structured phase.

The students' actions and reflections show that they perceived 'doing' the experiment and finding patterns in observations as most salient: theory was more or less pasted into the poster and the report without linking it to the experimental part. This conflicted with the purpose of scaffolding structures like the research meeting and the assessment criteria supporting the implementation of theory. However, the students did not express experiences involving problems due to a lack of a theoretical foundation to inform their inquiry. They did not focus on scientific theory during the inquiry process and were not prepared to prioritise and take advantage of structured scaffolding related to the inclusion of theory. Thus, a fruitful switching between space and structure did not occur in this situation where experiences in a phase with open space did not trigger a need for structured guidance. Interestingly, the structured phase prior to this open space did not contain guidance or constraints (e.g. task or template), indicating a need to enter problems and experiences where theory probably would become an issue.

Discussion and implications

The findings from the present study broaden our understanding of how a teacher's scaffolding strategies, providing students with structure and space, has consequences for students' learning from open inquiry. The analysis of Amir's design and scaffolding of the open-inquiry project revealed that he used The Scientific Method both as a *method of scientific inquiry* and as a *method for scaffolding* the students' inquiry projects. Taking into consideration that the goal of the project was to learn *about* scientific inquiry, the teacher's conflation of means and ends is problematic since he advanced a view of scientific inquiry as a simplified method built on the narrow epistemology associated with The Scientific Method (Windschitl et al., 2008). However, Amir provided *space* for the students to experience the complexity of scientific inquiry themselves and thereby possibly counteract some of the simplifications.

The initial structuring of the steps of scientific inquiry created constraints for students' subsequent problem solving. When the students performed their own inquiry struggling with procedural issues, they used skills like creativity and critical thinking (Hodson, 2009; Zion & Slezak, 2005) to solve emerging problems together. Moreover, these partly challenging experiences during periods of space were followed up by structure, where the students' reflections were guided, especially concerning procedural issues. Periods of productive space were characterised by the students' experiencing some of the complexity of the process of inquiry, allowing them to express their thoughts, ideas and tentative understanding. Moreover, these complex experiences provided an important impetus for meaningful scaffolding through periods of structure. Thus, the alternation between structure and space was valuable for the students' learning from open inquiry.

Furthermore, we found that the hair group was able to work independently through periods of space within the framework of The Scientific Method. The autonomy role (Hodson, 2009; Wells, 1999) was clearly driven by the students' interest in and ownership of the phenomenon, and it was encouraged by the teacher throughout the inquiry. However, the students' interests were mostly related to hands-on experiences, and this had consequences for the content of the reflections during structured scaffolding, dealing mostly with procedural issues. The essential features of scientific inquiry related to the role of theory in formulating a proper hypothesis and discussing one's own data within a theoretical framework did not become an integrative part of their inquiry; theory was handled as a separate entity. This can be explained by the teacher's use of scaffolding strategies; the simplified step-by-step method and the template implemented in the introduction and planning phase presented theory as a separate entity, not as something useful for the inquiry process. Later in the project, during the phase of performance and reflection, the implementation of scaffolding structures like assessment criteria and 'research meeting 2' focused more on the interplay between students' own data and relevant theory. However, this scaffolding did not have an impact on their inquiry process. Time was limited, and the students were more occupied with finishing their experiments and had not experienced the need to focus on theory on this stage. This interpretation is supported by the fact that, in the written products, their poster and report presented theory as a separate entity.

Considering the amount of science education literature revealing that 'hands-on' activities are often not 'minds-on' activities (e.g. Asay & Orgill, 2010; Roth, 2012; Tiberghien, Veillard, Le Maréchal, Buty & Millar, 2001), addressing how different scaffolding strategies constitute the students inquiry process becomes an important issue. The present case reveals that several scaffolding structures, in the form of tools and verbal guidance, were used for different purposes throughout the open inquiry. However, the study also indicates the need for scaffolding structures having an explicit focus on what type of theory is relevant and clearly supporting *how* theory informs an inquiry concerning the formation of a hypothesis and in the discussion of one's own results (e.g. Windschitl et al., 2008).

Scaffolding open inquiry using the notion of 'structure and space'

We believe that the notion of 'structure and space' (van der Valk & de Jong, 2009) is valuable to promote teachers' competence on how to scaffold open inquiry as a means to enhance more authentic scientific inquiry and promote active, autonomous learning. Moreover, we suggest that there exist a necessary tension and interplay between structure and space, creating what can be seen as a driving force providing structure, content and direction for the students' own experiences from open inquiry. The following model provides a thinking tool for teachers' planning of and reflection on how to combine structure and space to scaffold open inquiry.

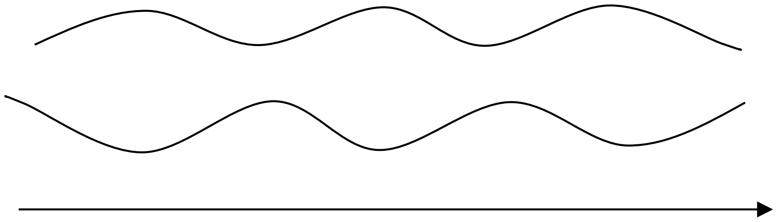

Figure 3. Scaffolding of the process of open inquiry, alternating between 'structure and space'

The model reveals how periods of space are both preceded and followed up by structure in the form of scaffolding to support essential features. For example, when the purpose is for the students to work creatively, developing their own ideas or struggling to inform their ideas with relevant theory (space), the teacher should reflect on what kind of scaffolding is appropriate for the students so they can work autonomously, developing researchable ideas. Moreover, periods of space need to be followed up by the teacher, for example, approving research questions and providing directions for the way forward. In addition, structured guidance is necessary to help the students reflect on their experiences and develop an explicit understanding of the epistemological dimensions that support their inquiries. Importantly, the presented case indicates (1) that structured phases attract students' interest when they are focused on challenges students have experienced in open phases and (2) that structured phases might involve guidance and constraints, leading students to make the kind of challenging experiences relevant for further guidance and the project's learning goal. Scaffolding normally involves less support as the students gain experience; however, new features of scientific inquiry emerge along the whole process, demanding subsequent support. Furthermore, the amount and type of scaffolding structure relative to space is, of course, dependent on the situated context: who the students are, what they know and the purpose of the scientific inquiry. The dynamic model of 'structure and space' might help increase the synergy between what Abd-El-Khalick (2012) calls the 'lived' (doing) and 'reflective' perspectives of scientific inquiry, providing a more robust inquiry learning environment.

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Bridging the Gap between Teaching and Research on Science Inquiry: Reflections based on Two Action Research Projects

Birgitte Bjønness and Gerd Johansen

Abstract

Collaborative action research provides opportunities for teachers and educational researchers to develop classroom practice as a joint achievement. In this paper, we reflect upon experiences from two extensive action research projects aimed at improving the practice of science inquiry at upper secondary schools. We experienced two main challenges regarding the processes: transitioning from the planning stages to implementation, and not utilizing sufficiently the distinct voices of the teacher and the researcher to improve the practice. We argue that the concepts of *tools* and *multi-voice* from activity theory provide valuable perspectives that can complement action research strategies. We propose that the joint development of concrete tools for use in the classroom might act to bridge the gap between research and the practice of science inquiry.

Keywords: collaborative action research, teacher-researcher, upper secondary school, science inquiry, activity theory

Introduction

> *(...) we had an idea last year that we were to enhance scientific talk amongst the students during science inquiry. And it failed. I could not contribute enough (into our collaboration) either on theory or concrete teaching methods to facilitate students talk. [Gerd, second author, interview, 10.06.10]*

This excerpt above is from a conversation between the teachers and researchers summing up two collaborative action research projects. In retrospect, it was – in spite of a common goal for change – difficult to bridge the gap between educational literature and the situated practice.

The authors were collaborating with experienced science teachers at upper secondary schools, for respectively three and two years with a common goal of improving the practices of science inquiries. The point of departure was a curriculum reform in Norway putting more weight on science inquiry (Norwegian Ministry of Education, 2006). It is well known from research literature that teachers struggle to implement inquiry (Capps & Crawford, 2012; Windschitl, 2004) and that teachers' opinions of what it means to do science inquiry are multifaceted (Asay & Orgill, 2010). According to Groundwater-Smith and Mockler (2011) we need research taking into account the local culture of the classroom where teachers have an empowered role in developing the knowledge to facilitate change. Furthermore, Keys and Bryan (2001) suggest a research agenda for science inquiry that are centred on the teachers' knowledge in order to produce research that bridges the gap between the practice and the research of inquiry. Thus, an approach built on collaboration between researcher and teacher aimed at developing the practice of science inquiry seemed for us to be of special value by taking account of the teacher's situated knowledge and the researcher's theoretical perspectives.

In the traditional form of educational action research, teachers strive to understand and to improve their practice through "action-reflection" cycles. This form takes account of the uniqueness of each educational setting and builds on the teachers' personal professional knowledge (Elliott, 1991). Subsequently, teachers and educational researchers have turned to collaborative forms of action research as a way to meet needs for improved practice, as well as field-based research. The insider(s) and outsider(s) are supposed to contribute with their different expertise and perspectives into the project (Herr & Anderson, 2005). The two approaches of educational action research provide different opportunities as well as challenges.

The purpose of this article is to discuss how to improve the process of collaboration in order to develop the practice of science inquiry by reflecting on the possibilities and challenges from two collaborative action research projects. The article builds on two Ph.D. projects, focusing on the teacher's role in supporting students during science inquiry (Bjønness, in progress;

Johansen, 2013) as well as semi-structured interviews with the participants. The article is both theoretical and reflective. It does not present findings in the traditional sense but rather reflections and insights exemplified and illustrated using empirical material from the two projects.

In the two action research projects, we experienced the same main challenges: going from planning new teaching approaches for science inquiry to actual change in action and the lack of different perspectives and voices as a foundation to improve the practice. Turning to the literature on action research, we found little concrete support for how to facilitate the process. However, we learned through the extensive fieldworks the importance of the joint development of *tools* for classroom activities that allowed for the perspectives of both the teacher and the researcher to meet.

The question driving the article is how the development of tools as a joint achievement between teachers and researchers can mediate change in practice. We argue that concrete tools for teaching science inquiry can act as an impetus for change when the development of tools are supported by educational literature as well as the situated practice. Thus, the distinguished voices of the teacher and researcher will complement each other.

Perspectives for change in school science inquiry

The perspectives presented here draw upon elements from the extensive research fields of: (1) science inquiry; (2) action research; and (3) activity theory.

Science inquiry as complex practice

There is an increased interest for inquiry based teaching following curriculum reforms all over the world (e.g., European Commission, 2007; National Research Council (NRC), 2000). However, the meanings associated with “inquiry” are multifaceted. There are two main definitions. The first definition of “inquiry” is the process that scientists use when they are conducting research along with the active learning process students engage in when they model professional scientists (Anderson, 2002). The second definition of “inquiry” refers to the activities in the classroom that facilitate the students’ learning of established science (NRC, 2000). In these action research projects, both forms of inquiries were represented.

In many ways, it is up to the individual teacher to decide or create his or her understanding and practice of what constitutes inquiry teaching (Anderson, 2002). However, literature reports on teachers’ lack of experience and knowledge on how to facilitate inquiry learning. This results in a poor learning outcome for students (Asay & Orgill, 2010). Moreover, studies on teacher’s epistemological assumptions of what it means to carry out science inquiry reveal simplistic forms of “the scientific method” (McComas, Almazroa, & Clough, 1998; Windschitl, 2004). Thus, teachers need help to form more sophisticated versions of inquiry because of tacit and culturally constructed beliefs that pervade practices, authoritative documents, classroom culture, textbooks, and media (Windschitl, 2004). Our intention was not to instruct teachers how to perform inquiry. Rather, it was to understand the situated, complex practice and develop the practice in collaboration with the teachers. It is critical to acknowledge that the local culture of the classroom will have a significant role in the interpretation of inquiry practice (Keys & Bryan, 2001). Moreover, we became more aware of how a teacher is part of the complex practice. The teacher must juggle between the knowledge of students, the knowledge of science and pedagogy, the teaching methods and the school "code". Thus, there are many problems and dilemmas with no clear solutions (Barnett & Hodson, 2001; Bjønness, Johansen, & Byhring, 2011).

Action research to change school practice

We do not intend to discuss educational action research per se; rather the intention is to bring in theory relevant to the challenges we experienced through our research projects. The main aim was to develop the situated practice of science inquiry and therefore there were not formulated explicit goals for the professional development of the teachers. This approach is close to more collaborative traditions of action research with the interest of improving a practice and contributing to the knowledge base of the relevant field (Herr & Anderson, 2005; Levin & Greenwood, 2001). However, we experienced that the process of developing the inquiry practice was empowering for both researchers and teachers (Carr & Kemmis, 2003). In the following, we will point at the two main challenges we experienced as researchers: (1) the difficulty to go from planning new practices to actual change, and (2) the lack of different perspectives and voices as a foundation to improve the practice.

In both projects, the first year of collaboration, facilitated by the researcher, followed the traditional action research spiral of iterative cycles of plan, act, observe and reflect (Elliot, 1991; Lewin, 1948). In the course of actions, we experienced that the transition between the cycles were challenging. In both practices, teacher and researcher decided to implement some changes in the following cycle but very little happened. However, we did not find that the issue of transitions was greatly problematized turning to action research literature. For example, in action research cycles, observations are the foundation for reflection. Yet there might be a danger that reflections become arbitrary because the teacher usually has limited time to observe. This also weakens the ability to scrutinize and think through the actions. Despite of much talk about reflection and reflexivity, according to Hall (1996), few accounts exist about how this is done. Further, since re-planning and new actions hinge on reflection of previous actions, it might be problematic to make good, relevant changes. If the wholeness of the situation and the underlying values are not part of the reflection, there is a danger that the action cycle is reduced to "social engineering" (Hellesnes, 1992; Herr & Anderson, 2005). The question is what kind of resources and methods of collaboration that facilitate an actual change of classroom practice.

In educational action research, the researcher is seen as a facilitator supporting the teachers in formulating a diagnosis and an action hypothesis to be tested in their classrooms (Elliott, 1991). Thus, it represents research *with* people and not *on* or *about* people (Heron & Reason, 2006), although, the form of collaboration may vary during the project (Herr & Anderson, 2005). When beginning to collaborate, trust is essential (Grant, Nelson, & Mitchell, 2008) in building a relation where there is enough "sameness" so that the participants speak of the "same" (McArdle, 2008). Moreover, action research is context dependent and it is concerned about the teachers' personal theories and values and how teachers "think-on-their feet" (Barnett & Hodson, 2001) in order to secure the students' learning process. However, if the teachers' perspectives are not challenged, there is a danger of reproducing the current practice (Dale, 1993). Thus, the different viewpoints provided by the teacher(s) and researcher(s) are important to preventing the researcher from developing the same "blind spots" as the teacher. So, what kind of collaborative environment can help the teacher to evaluate the context and the situations that appear? Theories can supply teachers with resources to see the contextual situations (Schön, 1983). In addition, a common language (McArdle, 2008), effort and competence for thinking with didactic concepts are important conditions for teacher collaboration (Dale, 1993) and collaboration between teachers and researchers as well.

In the action research literature, we found little concrete support about how collaboration between teachers and researchers can bridge the gap between situated practical knowledge and educational literature. However, in the literature of activity theory we found a theoretical understanding of the importance of *tools* and *multi-voice* as an impetus for change in a practice.

Activity theory and the concepts of tools and multi-voice

Our interest is not to make use of activity theory as a whole. Rather we borrow the concepts of *tools* and *multi-voice*, because they provide perspectives we believe are valuable to action research. Activity theory is an umbrella term for social science theories within the cultural-historical school building on the legacy of Vygotsky. Moreover, activity theory is contextual and oriented at understanding historically specific local practices, their objects, mediating artifacts and social organization (Cole & Engeström, 1993).

Tools to mediate practice

The idea of cultural *mediation* of actions, as formulated by Vygotsky, is central to activity theory (Cole & Engeström, 1993). The concept of mediation suggests that humans, for the most part, do not stand in direct contact with the surrounding world. Instead, we talk about the world and act in it using physical and intellectual tools that constitute integrated parts of our social practices. For instance, when using a microscope, we do not analyze the microscope as a separate entity and then study the "clean" human perceptions of the phenomenon. We must understand how thinking is performed by humans acting in social practices through artifacts (Säljö, 2001). According to Engeström (1999), artifacts include both tools and signs and, for the sake of simplicity, we will focus this article solely on *tools* as artifacts.

Mediation through tools is, according to Vygotsky (1978), both outwardly and inwardly oriented. Both aspects are present in every cultural tool (Cole & Engeström, 1993). For instance, when teachers introduce a practical supporting tool, e.g. IMRaD (introduction, method, results and discussion) for writing reports to the students, the tool has a bidirectional effect. It simultaneously mediates the activity of writing the report and modifies the students' concept of what it means to perform science.

Engeström (1999) underlines the necessity to differentiate between different ways of using tools by suggesting four types:

- *How tools* are used to guide and direct processes and procedures (e.g., meta-talk used to guide and constrain a discussion).
- *What tools* are used to identify and describe objects (e.g., theoretical concepts and concepts appropriated for practical use).
- *Why* tools are used to diagnose and explain the properties and behaviour of a practice. They can be used to reach a decision (e.g., the why question).
- *Where to tools* envision the future state or potential developments of a practice (e.g., explicate and examine collectively the solutions).

As there are different ways of using tools, there is nothing fixed in a tool that would determine that it could only be, for instance, a "why" tool (ibid.). A conceptual model may typically function as a dynamic diagnostic tool (why tool) but it may also be a frozen definition used only as a "what" tool to identify and classify phenomena.

Multivoicedness as an aspect of collaboration

We find that the aspects of collaboration in action research theory largely are focused on trust (Grant et al., 2008), sameness (McArdle, 2008) and reciprocity (Robertson, 2000) between the practitioner and the outsider. Moreover, power relations between the participants are seen as a part of the collaboration (Herr & Anderson, 2005). Power is regarded as inherent in every relation being both constructive as well as restrictive (Flyvbjerg, 2001). In collaboration between teacher(s) and researcher(s), the power relation will for instance dependent upon who has the authority to make decisions regarding different aspects of the action research project. However, the role of different perspectives and voices in changing a practice is perhaps less communicated in action research.

In activity theory, the tool-mediated construction of an action does not happen in a solitary manner or in harmonious unison. It is a collaborative and dialogic process in which different perspectives (Holland & Reeves, 1996) and voices (Engeström, 1995) meet, collide and merge. Engeström (1987) put emphasis on the crucial role of goal/problem construction in innovative learning. The initial existence of a shared problem cannot be taken for granted in work teams. Moreover, the formation of shared goal is a major collaborative achievement. When working together and developing a practice, there will always be different views related to one's interests, traditions and position. This is what Engeström calls multivoicedness: *"It (multivoicedness) is a source of trouble and a source of innovation, demanding actions of translation and negotiation."* (Engeström, 2001, p. 136).The term originated from Bakthin, and says something about how we deal with different viewpoints, by understanding that participants will have different perspectives and see this as a possibility for growth as well as a challenge. In developing a practice together, the teacher and researcher may not always agree on what they are going to achieve – and how to do it. This can be seen as at least two problems, first, the problem of not necessarily wanting the same outcome because of the different positions. Second, when developing a complex practice, the object (what one wants the result to be) can never be precise. It is, as Engeström so nicely put it, a moving target (Engeström, 2001).

Methods and context of practice

Methods

Two action research projects provide all the examples in this paper. In both projects we strived for trust and reciprocity. We practiced a division of labour where the teacher was responsible for the implementations in the classroom and the researcher for documenting the research process. Moreover, the teacher and researcher were planning and reflecting over the learning activities together, as well as formulating a common aim for the development of the inquiry practice. The researchers gathered empirical material at each school over two and three years respectively. The material included: video and audio recordings from the field work, students' products and teachers' handouts, reflection-notes, and conversations with the participants. This provided us with a rich empirical material. Moreover, as researchers in a complex practice, some of our after-field reflections are not directly emerging from our data material. Participating in the practices generates tacit insights and the researcher should not simply rely on the documented sources of the empirical material (Hammersley & Atkinson, 2007).

As part of our reflection and evaluation after the completion of the fieldwork, we conducted a semi-structured group interview (4 hours) with the teachers. In the interview, the teachers, Ellen and Amir, each made a summary of the action research and its impact on their classrooms. Then, the teachers and researchers talked together about the possibilities and constraints experienced during collaboration to improve practice. The interview was transcribed and in the transcription process some features such as tone of voice and pauses are lost, whereas others are gained (e.g., punctuation) (Kvale, 1996). However, the authors do not regard the interview as the blueprint of the participants' meanings or ideas. The interview, as well as the rest of the empirical material, are not statements directly representing the practice and research, but rather seen as a re-representation of what was perceived as salient at the time (Van Leeuwen, 2008). We present some part of the material that we believe is useful to explicate the ideas and understandings we have today.

Context of the two action research practices

Although we worked with teachers at two different schools with different approaches to science inquiry, there were similarities. The two upper secondary schools are both located in suburban areas outside the capital of Norway. In general, the groups of students were not very motivated with regard to the schoolwork or science. In addition, the teachers described some of the students as reluctant readers and writers.

Dale upper secondary school

The first author, Birgitte, worked together with an experienced science teacher named Amir for three action cycles to develop a twelve-week open inquiry science project. Other science teachers were also involved in the project in the first and second year but, because of different reasons, they did not continue into the third year. The collaboration consisted of meetings to plan the students' inquiry projects, ad-hoc meetings during the course of action, and evaluation after each cycle. The common goal was to develop a practice of open inquiry. This form of inquiry is often described in literature as a means to enhance more authentic science inquiry (e.g., Duschl & Grandy, 2008) and promote active, autonomous learning (e.g., Hodson, 2009). The students identify problems and ask questions, design and plan investigations, collect and analyze data, create explanations and reach conclusions, and then report their findings. Amir's main intention with the project was to increase his students' motivation for learning, understanding of the subject and grow their feeling of success concerning science.

Hill upper secondary school

The second author, Gerd, worked together with Ellen for two years in order to develop and improve structured inquiry practices, a more common form of inquiry in schools in which teachers determine the questions and specific procedures of the investigation (Asay & Orgill, 2010; Crawford, 2007). The aims of these inquiries were knowledge and understanding of scientific ideas and content in addition to procedural understanding. Ellen is a very experienced science teacher and she believes it is important to develop her own teaching practice. Ellen and Gerd had a special focus on how the use of multiple semiotic resources (e.g., visual images, tables and concrete objects) can support students' learning from science inquiries. To Ellen, it was important that the students in the class perceived science as manageable and that she, as teacher, could facilitate the subject matter so that the students mastered it.

The two practices: Tools and multi-voice

We do not intend the episodes from the two action-research projects presented here to represent exemplary instances in the development of the practices. Rather, they show some of the possibilities and constraints experienced in the collaboration between the teacher and researcher in a complex practice. We will present four snapshots from our practices to address the aim of this article and complement them with quotes from interviews to discuss how the development of tools, as a joint achievement between teacher and researcher, can mediate change in practice. We provide examples from two practices – Hill and Dale – for the *tool* and *multi-voice* concepts. We structure the snapshots by first introducing a problem concerning school science inquiry experienced by both practices. Next, we present a snapshot from the practices and include quotations from interviews. Finally, we put forward a short interpretation and discussion of the situation.

Developing tools for improving the practice of science inquiry

In both practices, we recorded little scientific dialogue neither in whole-class discussions nor in the individual science-inquiry student groups. These are well known problems from the literature of science education (Bennett, Hogarth, Lubben, Campbell, & Robinson, 2010; Driver, Newton, & Osborne, 2000). The first case exemplifies how lack of concrete tools may have prevented development of the students' inquiries while the second case shows the possibilities found in the joint development of a tool for the practice.

Hill case – first example

When Gerd started to work together with Ellen, she observed there was little talk between the students (age 16) concerning science. Because Gerd had read Vygotsky (1978) and was also very inspired by Mortimer and Scott (2003), she saw these theoretical perspectives as a salient approach to improve the small and structured inquiries. She proposed to Ellen to increase emphasis on the students' collaborative talk but it rather fizzled out and did not come to fruition. Using the example of ethical discussions as part of school science, Ellen said:

> *"They (the students) have to go into this – the students have to learn this… We (teachers) are so concerned with subject matter (the canon of science). This, I believe, is because we do not dare to go into other ways of discussing."*

Ellen's statement corresponds to findings by Oulton et al. (2004) claiming that few science teachers are prepared and know how to engage students in open discussions. Problems have also been reported about engaging students in collaborative talk about the subject matter (Bennett et al., 2010). This example illustrates how difficult it is to change the practice. However, we believe it is important that the researcher supports the teacher in dealing with what perhaps is a slightly scary new practice. Even if the teacher agreed in principle to the goal of "more scientific talk", in practice, it was problematic to carry it out. Furthermore, emotional support from a researcher is not enough when the teacher faces students who are reluctant to learn and where the teacher has little room to take risks. The teacher and researcher had not created comprehensive and useful *tools* for engaging students in collaborative talk and open discussions of science.

In order to discuss the role of tools (Cole & Engeström, 1993) in developing a practice we can start by envisioning what Gerd and Ellen could have done in the situation. First, together they could have used a "what tool" to identify and describe the problem with the existing practice. Relevant theoretical perspectives relating to talk in the classroom could have illuminated different approaches. This would perhaps require that the teacher read more literature of science education. However, in a world running on "teacher-time" this is difficult to do. Another possibility is that the researcher presented some perspectives, while the teacher and researcher discussed consequences and jointly developed "how tools" to guide and direct the students' learning processes. For example, how the teacher could structure the students' tasks to help them sort scientific claims. Following the implementation of a "how tool", the researcher and teacher could have used a "why tool" to diagnose and explain how the new practice worked in relation to the purpose. In addition, a "where to tool" could envision the future state or potential development. In the next case, we will provide an example from Dale upper secondary school to illustrate the advantage joint development tools to improve the situated practice.

Dale case – second example

In the case where Amir and his colleagues wanted to develop an open inquiry project, the teachers and the researcher made a diagnosis of the possibilities and the constraints in the project after the first year of collaboration. Birgitte then wrote a discussion paper supposed to represent a meeting point between the teachers' reflections on how the design worked out in the classrooms and the researcher’s theoretical knowledge. The researcher pointed out critical issues concerning the students’ inquiries that were characterized by trying and failing and little scientific talk among the students. In order to scaffold the students’ scientific talk, Birgitte made a suggestion for a *tool* inspired by how Amir let his students present their work to each other during the inquiry process. The tool was named “research meeting” and it was implemented in critical phases of the inquiry to facilitate the students’ support and challenge of each other’s’ work. Birgitte suggested that she could carry out the “research meetings” and Amir agreed with her. In the following quote, Amir revealed his opinion concerning the value of developing tools together:

> *”... you (Birgitte) show many initiatives that I don’t have to controvert because I see, when you bring in that initiative, that you have a good understanding of what we can expect from each other. For example the concept of ‘research meeting’, then we have a clever idea, and you have been given the possibility to practice it and see how it works, and I have learned from it without doubt. I have many positive opinions about that.”*

The example illustrates the significance of developing tools as an impetus for change in practice. The utterance also reveals the importance of trust between the teacher and the researcher (Grant et al., 2008). Furthermore, the “research meeting” had evolved from an existing practice developed by the teacher into a joint effort. The teacher had tacit understandings of what “works” and the researcher developed the tool further by using theory of cooperative learning (Johnson & Johnson, 1990). The implementation of the “research meeting” created an opportunity for Amir and Birgitte to reflect-on-action, to study students’ dialogues, and to observe if the tool facilitated the students’ scientific talk. The snapshot reveals the use of several types of tools. The “research meeting” serves as a “how tool” in respect to facilitating scientific talk amongst the students. It can also be seen as a “what tool” in the way it actually represents an important feature of science inquiry. The “discussion paper”, written after the first cycle of the action research can be seen as a tool itself. It represents both a “why tool” used to diagnose the open inquiry project and a “where to tool” envisioning the potential development of the project. However, the only substantial change in practice during the following cycle was the “research meeting” despite several other suggestions for improvements raised in the “discussion paper”. Thus, it can be questioned whether the “discussion paper” actually represented the teachers’ voice sufficiently for them to find it meaningful. This brings us to the role of multi-voice in changing a practice.

Challenges and possibilities of multi-voice for changing practice of science inquiry

When working together to develop a practice, there will always be different point of views relating to ones interests, traditions and position. This is what Engeström (2001) calls *multivoicedness*. Two snapshots from each of the action research projects illustrate challenges and possibilities with multi-voice. The point of departure is a well-known problem related to science inquiry in school, namely the gap between the domain of observables and the domain of ideas during science inquiry (Tiberghien, Veillard, Le Maréchal, Buty, & Millar, 2001), more commonly called the problem of "hands-on – mind-off". In a study of the effectiveness of practical work, Abrahams and Millar (2008) found that the teachers very often separated between teaching scientific knowledge and procedures of science inquiry. However, teachers strive to find good solutions to deal with these challenges (e.g., Hodson, 2009). The first example shows how lack of multi-voice may prevent change in practice and the second example illustrates the possibilities given by multi-voice.

Dale case - third example

Field observations and the students' written reports from the first year of action research revealed many "hands-on" activities with less focus on the "mind-on" part of science inquiry. Amir and Birgitte did not agree on how to handle the problem. The following quote reveals Amir's espoused beliefs concerning the group of students with low interest and achievement in science and the role of theory in their inquiry projects.

> *"… you know, the expectation that they should be able to connect a proper theory, in a professional way, I believe it's unrealistic (…). I think they (the students) need more maturity to be able to bring in the correct theory to describe what they do. Imagine you are in that age and (...) you don't read science and the only communication you have with science is what you learned at school. Suddenly you are expected to bring in theory that explains what you are doing, in my opinion it is a very professional expectation and it's difficult to get them to (do that)"*

The example illustrates the implicit disagreement between the teacher and researcher concerning the value of bringing in more theory in the students' inquiry projects. The historicity of the situated practice explains this. Amir discovered that the current practice – focusing mainly on the experimental part of science inquiry – motivates these students and, thus, he was reluctant to change. The teacher's main goals with the inquiry project were indeed to motivate the students and to give them feeling of mastery in science. Thus, Amir was reluctant when Birgitte suggested having an explicit focus on how to help students bring in relevant theory to inform their inquiries. In this example, the researcher and teacher did not manage to resolve their disagreement and take advantage of the possibilities multi-voice could represent in the collaboration. In the course of action, Birgitte understood how important it was for Amir to have an ownership to the suggested changes. Thus, a possible solution in this case could have been to provide Amir with relevant research literature knowing his interest in reading literature about science and education. Relevant literature could then represent another voice. The next example from Hill upper secondary school illustrates how multi-voice was an important element of improving a practice.

Hill case – fourth example

During the second year of Ellen's and Gerd's collaboration, they planned lessons together and tried to find good resources ("how tools") that might support students' meaning-making of structured science inquiries. Ellen described the collaboration:

> *"We think together. That I perceive as working well, because the thoughts often become very unsystematic, but to have someone to think together with on a common project then it becomes more systematic."*

From a reflective position, this "thinking-together" has two important features. First, the teacher and researcher exchange ideas about apt resources connected to the structured inquiries. The resources are discussed and scrutinized for what they can offer to students' meaning-making (e.g., Ogborn et al. 2004). A common goal exists but the situation allows for multi-voice: views are explicated and argued for, yet agreement is not required. Vital in this multi-voice collaboration was to bring in other voices for instance textbooks or internet sites. To make a critique of a "third party" is perhaps easier than to make a critique of each other's position and made it possible to practice "why tools". Moreover, the teacher has veto concerning what he/she implements in the classroom. This means that the teacher is the chief judge about what to do. Second, through "thinking together" – letting different voices contribute – it was easier to make concrete tools for implementation, as long as the teacher had the final decision for how to implement the tools.

Some final reflections

In this article, we set out to discuss how teachers and researchers can bridge the gap between educational research and teaching. Our position is not to seek a total overlap between these two domains. Instead, it is to ensure that the research domain aids in the development of teaching practices and that the situated teaching provides important perspectives into educational research. However, teachers rarely get the time to see the whole picture of their practice and many live isolated from research findings and theoretical debates about key issues of science education (Hodson & Bencze, 1998): As a consequence they often reproduce their own practice. Further, Hodson and Bencze (1998, p. 692) state:

> *"Because teachers' views are built up over a long period and are burnished in the furnace of everyday practice, challenges must be vigorous and explicit if change is to occur".*

Through the authors' experiences during the two action research projects and reflection afterwards, we suggest that the concepts of multi-voice and tools are useful supplements to a collaborative action research approach. We advocate that multi-voice and tools provide an opportunity to challenge an established practice.

There is a gap between teacher and researcher in action research due to different roles, positions and focus (Herr & Anderson, 2005) thus what Engeström (2001) calls multi-voice. In our opinion, the teachers and researchers must be explicit about their positions throughout the entire collaboration. The researcher and teacher can open up and explicate their different positions, as in the case of Ellen and Gerd, where they challenged each other in their understanding of "good resources for learning". The concept of multi-voice provides an understanding of teachers and researchers' different point of views as a *force* for developing a practice. Further, the concept of multi-voice raises the awareness of relevant theory as a significant voice itself and contributes to the aim of collaboration.

Literature on action research stresses the importance of trust (Grant et al., 2008) and sameness (McArdle, 2008) in the relationship between teacher and researcher. Trust is perhaps especially important in research on educational practices as the practice of teaching is closely connected to the teacher as person (Barnett & Hodson, 2001). Thus, if there is little trust and sameness in the relationship between teacher and researcher, multi-voice might be experienced as threatening. This calls for, in our opinion, a considerate balance between trust, sameness and multi-voice in the process of developing a practice. Challenges that are too profound may lead to withdrawal and, on the other hand, small challenges may lead to little development of the practice. Low or implicit challenge was perhaps the case in the collaboration between Birgitte and Amir on strengthening students' use of theoretical input in their science inquiry (example 3). However, perhaps both Birgitte and Amir had explicated and argued sufficiently for each of their positions and the matter was not resolved according to the researcher's ideas because Amir based his decision primarily upon his situated knowledge. This reveals another problem when working together developing a practice: who is going to decide what? A teacher must perceive that the change in practice will be both manageable to carry out and beneficial for the students. If not, the teacher will continue the existing practice. In classrooms where most of the students are reluctant learners, as in the present cases, there is a tendency for the teachers to concentrate their teaching on repeating facts and rote learning (Hodgson, Rønning, Skogvold, & Tomlinson, 2010; Yerrick, Liuzzo, & Brutt-Griffler, 2012). In such situations, there is perhaps a special need for negotiations between the teacher and researcher that are based on the situated classroom practice. In this case, the authors propose that joint development of concrete tools to mediate the change in classroom activities could have overcome the teacher's resistance to change and explicate the researcher's intentions.

There will always be a gap between teaching and educational research. The research provides perspectives to understand education in general and, in our cases, science inquiry in particular while teaching provides perspectives on the situated practice. However, the teacher might not have experienced educational literature as relevant; it has little to contribute to his or her particular practice. Moreover, perhaps, research is too often prescriptive in the sense that it gives teachers long lists of "you ought to do". To avoid patronizing the teachers' practice, the authors experienced that working together to design tools to be used in the classroom (how tools) proved to be a driving force for sustainable change. In addition, the process of translation and negotiation between teacher(s) and researcher(s) can be seen as a possibility for personal growth. Reciprocity, trust and multi-voice were part of the relationship that made it possible to make "how tools" mediating the actual classroom activities. The teachers found the development of "how tools" useful within their working frames with limited time. The other types of tools described by Engeström (1999) – why tool, what tool and where to tool – are important to providing support for reflections outside the classroom activities and to direct further development. The shape and the use of these reflective tools outside the classroom have direct influence on the relationship between the teacher and the researcher ensuring trust and multi-voice. The tool changes the users as well as the activity upon which it mediates (Cole & Engeström, 1993). The point is that a tool, in addition to influencing an activity, also has an effect on the teacher using it because he or she will look differently on their own practice – and perhaps see new possibilities. This was the case when Ellen and Gerd developed tools, such as pictures and illustrations, to increase students learning from science inquiry. Concerning the use of illustrations in her teaching, this collaborative work increased Ellen's general consciousness on resources for teaching and learning.

We argue that tools are in-between theory and practice: uniting a situated understanding and educational theory. Thus, tools might act to bridge the gap between research and practice. The teacher has to be able to use the tools in the rough and tumble of the science inquiry – not to fall back on previous practice. The tools applied as a change-agent in the classroom need therefor to be concrete, robust, made and re-made to fit the situated practice. If users consider the tool to be between theory and practice then the development of the tool needs to draw from the situated practice and the tool's theoretical foundation. However, herein lays one of the problems when transferring a tool from one situation to another. The tool "research meeting" as described in the second example draws on two theoretical positions: (1) socio-cultural perspectives of oral language as a vehicle for students' understanding of the inquiry process and results and (2) peer-review processes in “professional” science to assess and argue for methods and results. Thus, the “research meeting” has epistemological underpinnings connected to the production of science and to learning science. The tool made in one situated classroom practice, will be changed when it meets another practice. Sannino and Nocon (2008) emphasize that sustainability of innovations does not only refer to local continuity but also to diffusion and adoptions in other settings. This generates a problem: how to convey the epistemological foundations for the tool; they might be lost and all that remains is the “shell” of the tool. From our position, one must emphasize robustness when developing a tool to ground it in epistemology. However, the teacher will adapt the tool into his or her situated practice, and we firmly support Ellen’s statement:

> *If I get ready-made things (tools), then I think it’s a bit difficult to use them, but tools where you are sitting together in a creative process – then I make them my own.*
> *[Ellen, post-interview, 10.06.10]*

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