Unit of Chemistry Teacher Education
Department of Chemistry
University of Helsinki

NATURE OF SCIENCE FOR CHEMISTRY EDUCATION

DESIGN OF CHEMISTRY TEACHER EDUCATION COURSE

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ACADEMIC DISSERTATION

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ABSTRACT

Nature of science (NOS) describes what science is, how it works, how scientists operate, and the interaction between science and society. As a crucial element of scientific literacy, knowledge about NOS is widely recognized as one of the key aims of chemistry education. To enhance students' understanding of NOS, teachers need adequate understanding of NOS as well as sufficient pedagogical content knowledge related to NOS for translating their understanding of NOS into classroom practice.

This thesis reports an educational design research project on the design and development of a pre-service chemistry teacher education course on NOS instruction. Educational design research is the systematic study of the design and development of educational interventions for addressing complex educational problems. It advances the knowledge about the characteristics of designed interventions and the processes of design and development.

The thesis consists of four interconnected studies and documents two iterative design research cycles of problem analysis, design, implementation, and evaluation. The first two studies describe how NOS is presented in the national frame curricula and upper secondary school chemistry textbooks. These studies provide a quantitative method for analysis of representations of NOS in chemistry textbooks and curricula, as well as describe the components of domain-specific NOS for chemistry education.

The other two studies document the design, development, and evaluation of the goals and instructional practices used on the course. Four design solutions were produced: (i) description of central dimensions of domain-specific NOS for chemistry education, (ii) research group visits to prevent the diluting of relevance to science content and research, (iii) a teaching cycle for explicit and structured opportunities for reflection and discussion, and (iv) collaborative design assignments for translating NOS understanding into classroom practice. The evaluations of the practicality and effectiveness of the design solutions are based on the reflective essays and interviews of the pre-service teachers, which were collected during the course, as well as on the four in-depth interviews of selected participants, collected a year after they had graduated as qualified teachers.

The results suggest that one critical factor influencing pre-service chemistry teachers' commitment to teach NOS was the possibility to implement NOS instruction during the course. Thus, the use of collaborative peer teaching and integrating student teaching on NOS instruction courses is suggested as a strategy to support the development of the attitudes, beliefs, and skills necessary for teaching NOS. And even though the outside forces of school culture (e.g. school community, curriculum, textbooks) tend to constrain rather than support novice teachers' efforts to implement new practices, the results also demonstrate that a pre-service teacher education course can be successful in producing innovators or early adopters of NOS instruction. Thus it might be one of the first steps in the challenging task of injecting NOS instruction into the chemistry curriculum for enhancing students' understanding of NOS and strengthening their scientific literacy.

Keywords: chemistry education, teacher education, educational design research, nature of science, philosophy of chemistry

TIIVISTELMÄ

Pelkkä tieteen sisältöjen eli tieteellisen tutkimuksen tuottamien mallien ja teorioiden viestiminen ei anna totuudenmukaista kuvaa kemiasta tai mistään muustakaan tieteestä. Oleellinen osa tieteellistä yleissivistystä on myös ymmärtää, millaista tietoa tieteellinen tieto on ja miten sitä tuotetaan. Näihin kysymyksiin vastauksia tuottavat tieteentutkimuksen eri alat kuten tieteenfilosofia, -historia ja -sosiologia. Tieteentutkimuksen merkitystä kouluopetukselle on pohdittu jo vuosikymmeniä. Opetuksen tutkimuksessa aihealuetta on viimeisten vuosikymmenten ajan kuvattu käsitteellä luonnontieteen luonne (engl. nature of science). Luonnontieteen luonteen ymmärryksen kehittämistä pidetään kautta maailman yhtenä tiedeopetuksen keskeisimpänä tavoitteena.

Luonnontieteen luonteen opettamista käsitellään tutkimuskirjallisuudessa yleensä yhtenäisen tiedeopetuksen näkökulmasta. Jokaisella tieteenalalla on kuitenkin omat erityispiirteensä, jotka tulisi huomioida myös luonnontieteen luonteen opetuksessa. Yleisen luonnontieteen luonteen ymmärryksen lisäksi voidaankin puhua tieteenalakohtaisesta luonnontieteen luonteen ymmärryksestä. Tällaisen kemian luonteen määrittelyn kannalta keskeinen tieteentutkimuksen ala on kemian filosofia, joka pyrkii määrittelemään ja kuvaamaan kemialle ominaisia käsitteitä, malleja ja selityksiä sekä pohtimaan kemian tutkimukseen liittyviä metodologisia, eettisiä ja esteettisiä kysymyksiä. Koska kemian filosofiaa on omana tutkimusalanaan tutkittu vasta parikymmentä vuotta, sen huomioimista opetuksessa on aiemmin tutkittu varsin vähän.

Tämä väitöskirjatutkimus raportoi kehittämistutkimuksen, jonka aikana suunniteltiin, toteutettiin ja kehitettiin kemian luonnetta käsitellyt opettajankoulutuskurssi *Kemia tieteenä*.

Väitöskirja koostuu neljästä osatutkimuksesta. Kaksi ensimmäistä osatutkimusta arvioivat kemian luonteen opetuksen nykytilaa analysoimalla ja vertailemalla pohjoismaisia lukiotason valtakunnallisia opetussuunnitelmia ja oppikirjoja. Opetussuunnitelmien ja oppikirjojen analyysi perustui opetuksen tutkimuksen kuvauksiin luonnontieteen luonteen keskeisistä piirteistä sekä kemian filosofian tutkimuksen kuvauksiin kemian erityispiirteistä. Tulosten mukaan opetussuunnitelmat ja oppikirjat käsittelevät kemian luonteen aihealuetta vähän ja yksipuolisesti. Esimerkiksi tiedeyhteisön merkitys uuden kemiallisen tiedon tuottamisessa mainittiin suomalaisissa oppikirjasarjoissa vain ohimennen.

Väitöskirjan toiset kaksi osatutkimusta kuvaavat *Kemia tieteenä* -kurssin tavoitteiden ja opetuksellisten ratkaisuiden suunnittelua, kehittämistä, toteuttamista ja arviointia. Tutkimusprojektissa tuotettiin neljä kehittämistuotosta: (i) kuvaus luonnontieteen luonteen keskeisistä piirteistä kemian opetuksen näkökulmasta, (ii) tutkimusryhmävierailut tapana yhdistää teoreettinen tieto kemian luonteesta autenttisiin esimerkkeihin kemian tutkimuksesta, (iii) kemian luonteen ymmärrystä kehittävä reflektiivinen ja yhteistoiminnallinen opetussykli sekä (iv) tapa toteuttaa suunnittelutehtäviä, jotka edistävät aihealueen huomioimista kouluopetuksessa.

Opetuksellisten ratkaisuiden tehokkuuden ja käytännöllisyyden arviointiin käytettiin sekä kurssin opiskelijoiden kirjallisia vastauksia oppimistehtäviin, kurssin lopussa toteutettuja ryhmähaastatteluita että neljää vuosi opiskelijoiden valmistumisen jälkeen toteutettua teemahaastattelua. Tulosten mukaan erityisesti mahdollisuus toteuttaa kemian luonteen huomioivaa opetusta jo kurssin aikana tuki opettajien sitoutumista huomioida aihealue opetuksessaan myös valmistumisen jälkeen. Opettajien sitoutumista aihealueen opettamiseen voitaisiin kehittää edelleen esimerkiksi vertaisopetuksella tai kurssin aikana toteutetulla opetusharjoittelulla.

Vaikka sekä aikaisemman että tämän tutkimuksen valossa uusien opetuksellisten lähestymistapojen omaksumisen edistäminen opettajankoulutuksessa on haastavaa, osa *Kemia tieteenä* -kurssin opiskelijoista innostui aiheesta ja ryhtyi opettamaan aihealueen sisältöjä. Heitä voidaan kuvata kemian luonteen opettamisen varhaisina omaksujina, jotka opettavat aihealuetta oppikirjojen sisältöjä laajemmin sekä mahdollisesti houkuttelevat muitakin kiinnostumaan aihealueesta. Aihealueen opetuksen valtakunnallisen kehittämisen kannalta on kuitenkin keskeistä, että kemian luonteen ymmärtämiseen liittyvät tavoitteet huomioidaan tulevaisuudessa paremmin sekä opetussuunnitelman perusteissa, oppikirjoissa että ylioppilaskirjoitusten tehtävissä. Tutkimuksen tuloksena syntynyttä kuvausta kemian luonteen keskeisistä piirteistä voidaan käyttää esimerkiksi määriteltäessä aihealueen tavoitteita opetussuunnitelman perusteisiin.

Avainsanat: kemian opetus, opettajankoulutus, kehittämistutkimus, luonnoiteteen luonne, kemian filosofia

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Helsinki, October 21st 2012,

Veli-Matti Vesterinen

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications, which are referred to in the text by their roman numerals:

I Vesterinen, V.-M., Aksela, M., & Sundberg, M. R. (2009). Nature of chemistry in the national frame curricula for upper secondary education in Finland, Norway and Sweden. *NorDiNa, 5*, 200–212.

II Vesterinen, V.-M., Aksela, M., & Lavonen, J. (2011). Quantitative analysis of representations of nature of science in Nordic upper secondary school textbooks using framework of analysis based on philosophy of chemistry. *Science & Education,* published online (pre-print) 18 October 2011.

III Vesterinen, V.-M., & Aksela, M. (2009). A novel course of chemistry as a scientific discipline: How do prospective teachers perceive nature of chemistry through visits to research groups? *Chemistry Education Research and Practice, 10*, 132–141.

IV Vesterinen, V.-M., & Aksela, M. (2012). Design of chemistry teacher education course on nature of science. *Science & Education,* published online (pre-print) 23 June 2012.

CONTENTS

1 INTRODUCTION

Since being introduced over 50 years ago, scientific literacy has become a central educational objective of science education worldwide (Hurd 1998, Oliver et al. 2001, Dillon 2009). In fact, scientific literacy is often used as an umbrella term covering most aims of science education (DeBoer 2000, Laugksch 2000). Knowledge about characteristics of science often referred to as nature of science is considered to be a central element of such scientific literacy (see e.g. Hodson 2008). This thesis argues that a domain specific description of nature of science is needed for chemistry education, and that such description of nature of chemistry should acknowledge interdisciplinary research in the field of philosophy of chemistry.

This thesis documents an educational design research project on the design and development of a pre-service chemistry teacher education course on nature of science instruction. The research project had two interconnected goals: (i) to produce a course supporting chemistry teachers' understanding of nature of science within the context of chemistry education as well as their skills in implementing that understanding into their everyday classroom practice; and (ii) to contribute to the knowledge about supporting implementation of new innovative practices such as nature of science instruction through pre-service teacher education.

Following the theoretical model of educational design research presented by Edelson (2002), the overview of the studies presented here seeks answers to four questions. *The domain theories* presented in this study seek answers to the following questions:

1. Outcome theories: What are the possible outcomes of a chemistry teacher education course on nature of science?
2. Context theories: What are the challenges associated with the design of such course?

The design framework and *design methodologies* produced during the design project seek answers to the following questions:

3. Design framework: What are the characteristics of a successful chemistry teacher education course on nature of science?
4. Design methodology: What are the characteristics of a successful design process for developing such course?

2 BACKGROUND

In the first section (Section 2.1) of this chapter, the rationale for the need of nature of science in chemistry education as well as for the need of context specific descriptions of nature of science is presented. The section also discusses why interdisciplinary research field of philosophy of chemistry should contribute to descriptions of nature of science for chemistry education. The second section (Section 2.2) provides information on the context of the study by describing the chemistry teacher eduation program and the chemistry teacher education program course designed and developed during the research project.

2.1 THEORETICAL BACKGROUND

2.1.1 SCIENTIFIC LITERACY

The concept scientific literacy was introduced by in late 1950s by Richard McCurdy (1958) and Paul Hurd (1958). Although it initially focused on improving the public understanding of science and support for science and industrial programs (see Fitzpatrick 1960; Waterman 1960), during the following decades the concept was debated and reconceptualized countless of times.[1] Preceded by the views of science presented in Thomas Kuhn's (1962) *The Structure of Scientific Revolutions,* during the 1960s and 1970s the new academic knowledge of science and technology studies deeply challenged the traditional positivist view of science portrayed on curricula and science textbooks. The historical, philosophical and sociological analysis of the scientists' work provided a new view of science as a socially embedded enterprise. Eventually this new view of science studies had effect also on school science education. Many teachers were also disappointed about the outcomes of traditional science education and wished to promote social awareness in their students. Hence, in the late 1960s, Pella et al. (1966) suggested that scientific literacy comprises not only the knowledge about the basic notions of science, but also the understanding about the ethics that control scientists in their work, the interrelationships of science and society, and the differences between science and technology.

Inspired by the new academic research on science and technology studies as well as environmental and civic movements, the social context and science-technology-society movement (see e.g. Aikenhead 1994, 2003; Pedretti and Nazir 2011) began dominating the conceptualizations of scientific literacy during the 1980s and 1990s (DeBoer 2000). In the *NSTA* position statement from 1982 entitled *Science-Technology-Society: Science*

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[1] See e.g. Agin (1974), Daugs (1970), Gabel (1976), Hurd (1975), Klopfer (1969), O'Hearn, (1976), Pella (1967), Shen (1975).

Education for the 1980s stated that the goal of school science education was "to develop scientifically literate individuals who understand how science, technology, and society influence one another and who are able to use this knowledge in their everyday decision-making" (National Science Teachers Assotiation 1982, p. 1, quoted in Yager 1996, p. 4). Need for a change towards more contextual science education and realigning the focus of science education towards the goal of scientific literacy for all was supported also be the publication of *A Nation at Risk* report by the *National Commission of Excellence in Education* (1983). It documented how, in spite of the efforts following the Sputnik crisis, the vast majority of students were still not interested in science and learned very little science.

The disenchantment with the results of traditional science education programs has not been the only driving force behind the change. When the vocabulary of sustainable development was defined in the *Brundtland report* by the *World Commission on Environment and Development* (United Nations 1987), environmental problems were linked to issues of global equity and justice, such as income and resource distribution, poverty alleviation, and gender equality. Influenced both by the tradition of liberal education as well as civil rights and environmental movements, researchers such as Chen and Novik (1984), and Thomas and Durant (1987) have seen scientific literacy as a means to promote more democratic and equal decision-making. Today scientific literacy is often connected with global problems of ecological, social and economic sustainability such as climate change (see e.g. Hodson 2003; Hollbrook 2009). The new conceptualizations of scientific literacy are thus closely related with the socioscientific issues movement (see e.g. Zeidler et al. 2005).

Researchers and policymakers still justify the need for scientific literacy on variety of rationales, such as usefulness of scientific knowledge for everyday life, learning transferable skills for problem solving, personal autonomy on science realted issues, decision making as consumers, democratic participation in political issues related to science, ethical responsibility of scientists, politicians, and citizens, supporting sustainable development, as well as transmission of culture of science as an integral part of our cultural heritage (see e.g. Laugksch 2000). Whatever the rationales behind them, most conceptualizations of scientific literacy seem to agree that one central element of scientific literacy is to understand what science is, how it works, and how scientists operate (see e.g. Hodson 2008). In the research literature the concept of nature of science (NOS) is gaining ground as the most common representation of such essentials of informed and updated picture of science. Hence, as a crucial element of scientific literacy, NOS is now widely recognized to be a key concept in the curricular aims of science education all over the world.[2]

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[2] See e.g. Adúriz-Bravo and Izquierdo-Aymerich (2009), Hodson (2003), Matthews (2004), McComas and Olson (1998).

2.1.2 NATURE OF SCIENCE

In developing scientific literacy, the meta-knowledge that arises mainly from the historical, philosophical and sociological studies of science plays an integral part. The vast and complex literature on the history, philosophy, and sociology of science in science education dates back to at least the early 1960s.[3] Within the last twenty years, suitable educational answers to questions what science is, how it works, and how scientists operate, have been described by various definitions of nature of science (NOS). Although philosophers, historians, and sociologians are quick to disagree with the specific issues regarding NOS, it is argued, that there are elements of NOS that are seen uncontroversial enough as well as accessible enough to be discussed in school science education (Lederman et al. 2002). Although some differences and variations in focus of descriptions of such central dimensions of NOS can be found, there are strong similarities amongst the features of science presented by different research groups.[4]

Although NOS has traditionally been influenced mainly by the philosophy of science and focused on the epistemological dimensions of science, there are number of other fields of science studies and interdisciplinary fields of science that should contribute to informed and updated picture of science. During the last four decades, research on fields such as sociology, psychology, antropology, economics, gender studies, and sustainability science has provided new perspectives on science and scientific practice. Thus it is no wonder, that there remains some difference of opinion about the description of central dimensions of NOS focusing on just few consensual aspects, and about the role such descriptions should have on school science education (see e.g. Clough 2007; Matthews 2012).

As understanding NOS is now recognized as a crucial element of scientific literacy, it is also recognized as one of the key aims of chemistry education. As there are cultural, methodological and epistemological differences between the different domains of science (see e.g. Schwartz and Lederman 2002), there is also a need for context specific descriptions of NOS. Philosophy of chemistry, which highlights the domain-specificity of chemical knowledge and culture (see e.g. Dalgety et al. 2003), can be used in characterizing such context specific descriptions of nature of chemistry.

2.1.3 NATURE OF CHEMISTRY

As understanding NOS is widely recognized as a crucial element of scientific literacy, it is also recognized as one of the key aims of chemistry education. As there are cultural, methodological and epistemological differences between the different domains of science (see e.g. Schwartz and Lederman 2002), there is also a need for context specific descriptions of NOS. Philosophy of chemistry, which examines the disctinctive nature of chemical

[3] For an overview see e.g. Hodson (2008, 2009), Lederman (1992), Matthews (1994).

[4] See e.g. Lederman (2007), Matthews (2012), McComas and Olson (1998), Osborne et al. (2003).

knowledge and practice highlighting the domain-specificity of chemical knowledge and culture (see e.g. Dalgety et al. 2003; Erduran & Scerri 2002), can be used in characterizing such context specific descriptions of nature of chemistry.

Traditionally, philosophy of science has concentrated on "what is viewed as the paradigm science, that is to say physics" (Scerri 2001, p. 165). Since the more naturalistic accounts of science began dominating the fields of academic science studies during the last thirty years, philosophers of science have turned their attention also towards other scientific disciplines. For example philosophy of biology is today an established field of study (see e.g. Sober 1993). From 1990s, there has also been a growing interest on the interdisciplinary field of philosophy of chemistry.[5]

The philosophy of chemistry is a subgenre of science studies, which deals with the practices, models and concepts of chemists with a goal of gaining a better understanding of chemistry as a scientific discipline. As a relatively new area of science studies, significant amount of research on the field of philosophy of chemistry has been focused on defining its territory (see e.g. Lombardi and Labarca 2005). The main issue of this discussion has been the claim of reduction of chemistry to physics.[6] According to Scerri and McIntyre (1997) the reduction of most of the chemical concepts to physics is not possible, as chemical concepts like bonding or molecular structure can only be expressed at the chemical level.

Although issues like the nature of chemical substances (e.g. van Brakel (2000) and the role of instrumentation in producing chemical knowledge (see e.g. Baird 2000) are still being discussed, the research on the field of philosophy of chemistry has also moved beyond the epistemological and ontological issues of chemistry. Topics on the journals devoted to the field of philosophy of chemistry have encompassed a broad spectrum of academic science studies from aesthetics of chemical visualizations (see e.g. Spector and Schummer 2003) to cultural studies of chemistry in fiction (see e.g. Ball 2006). Within the last ten years there has also been a growing interest in the application of domain specific knowledge provided by the multidisciplinary field of philosophy of chemistry to chemistry education, and especially to

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[5] See e.g. journals *HYLE: International Journal for Philosophy of Chemistry* and *Foundations of Chemistry* as well as Bhushan and Rosenfield (2000), Baird et al. (2006), Kovac (2004), Scerri (2007), van Brakel (2000). For an overview of the histofy of the philosophy of chemistry see van Brakel (1999).

[6] In philosophy of science reduction is defined as the explanation of scientific theories and phenomenon with more accurate theories or more fundamental phenomenon. In natural sciences reductionism is usually seen as the reduction of other natural sciences to physics. Reductionism implies the unity of science. In physical sciences the idea of reduction is apparent in the search for the grand unification theory that could explain all the physical phenomena in a one coherent theory. The reduction of chemistry to physics has been extensively discussed in the philosophy of chemistry, especially by chemist-philosopher Eric Scerri (e.g. 1991a, 1991b, 1994, 2000).

chemistry teacher education.[7]

The need for philosophy of chemistry in chemistry teacher education has been justified by the teachers' need to understand the epistemology of chemistry for coordination of the content knowledge for teaching:

> Schwab (1962) argued that expertise in teaching requires both knowledge of a content of a domain and knowledge about the epistemology of that domain. Teachers develop the necessary capability of transforming subject into teachable content only when they know how the disciplinary knowledge is structured. Numerous studies (e.g. Lampert 1990; Shulman 1987) have illustrated the centrality of disciplinary knowledge in good teaching. The challenge facing teacher education is that teachers in general have had little exposure to issues of chemical knowledge beyond content knowledge.
>
> (Erduran et al. 2007, p. 986)

For example, Mansoor Niaz has extensively written about using history and philosophy of chemistry in supporting conceptual change in teaching general chemistry (for an overview, see Niaz 2008). There is still lack of evidence on to what extent the teacher's epistemological understanding truly supports students learning traditional science content. Thus the need for perspectives from philosophy of chemistry in teacher education is perhaps best justified by the need for context specific approaches for NOS instruction (see e.g. Hodson 2009). In spite the need for such context specific NOS, the central dimensions of nature of chemistry have not been specified before.

2.1.4 PEDAGOGIC CONTENT KNOWLEDGE FOR NATURE OF CHEMISTRY

Implementing innovative new teaching practices such as NOS instruction demands understanding of the new domain of knowledge, as well as skills and strategies to translate that knowledge into classroom practice (see e.g. Abd-El-Khalick 2005, Russell et al. 2001). The knowledge base needed in transforming the teacher's understanding to a form accessible to students has been described with the concept of pedagogical content knowledge. In his influential pair of articles, Lee Shulman (1986, 1987) first introduced pedagogical content knowledge as a component of teachers' professional knowledge. Rather than considering subject knowledge and pedagogy as mutually exclusive knowledge domains, he proposed that teacher education programs should combine the two to develop teachers' pedagogical content knowledge.

According to Cochran et al. (1991) subject teachers differ from other experts, such as scientists or science writers, not only in the quality and

[7] See e.g. Chamizo (2007, 2011), Erduran (2000, 2001, 2005, 2007), Erduran and Duschl (2004), Erduran and Scerri (2002), Erduran et al. (2007), Fernández-González (2011), Laszlo (2011), Lomardi and Labarca (2007), Ribeiro and Pereira (2012), Scerri (2001, 2003); Sjöström (2007, 2011), Taber (2003), Talanquer (2007, 2011).

quantity of their subject matter knowedge, but also on how that knowledge is organized:

> For example, experienced science teacher's knowledge of science is structured from a teaching perspective and is used as a basis for helping students to understand specific concepts. A scientist's knowledge, on the other hand, is structured from a research perspective and is used as a basis for the construction of new knowledge in the field.
>
> (Cochran et al., p. 5)

Pedagogical content knowledge is thus a synthesis of at least two different types of knowledge: subject matter knowledge and pedagogical knowledge. Proficiency in pedagogical content knowledge means moving beyond the mere comprehension of the knowledge, "to becoming able to elucidate subject matter in new ways, reorganize and partition it, clothe it in activities and emotions, in metaphors and exercises, and in examples and demonstrations, so that it can be grasped by students" (Shulman 1987, p. 13). Robust pedagogical content knowledge in NOS would enable teachers to "talk comfortably about NOS issues, lead discussions, respond quickly and appropriately to questions, clarify misconceptions, provide good examples, and so on" (Hodson 2009, p. 74).

Although there are numerous conceptualizations of pedagogical content knowledge, there is consensus that it is developed in a reflective process rooted in teachers' classroom practice (van Driel et al. 1998), and hence developing pedagogical content knowledge demands possibilities to contextualize teaching practice within theory and theory within practice (see Russell et al. 2001). Thus, for supporting pre-service teachers pedagogic content knowledge about nature of chemistry one cannot concentrate only on providing the teacher with adequate understanding about NOS issues. To acquire adequate skills and stragies for teaching NOS, the teachers should be also provided with possibilities to contextualize their understanding of the content within classroom practice. Although such an approach might have its limitations (see e.g. McComas et al. 1998), the need to contextualize content within teaching practice supports the integration of NOS content and pedagogic dimensions of teaching NOS on same courses.

2.2 CONTEXT OF THE STUDIES

The Chemistry Teacher Education Unit at Department of Chemistry of the University of Helsinki has around 200 pre-service chemistry teacher students, studying chemistry either as a major or a minor subject.[8] The aim

[8] In Finnish education system, the science subjects (biology, chemistry, geography, and physics) are taught as separate subjects by subject teachers specialized in the given subjects from the seventh year of comprehensive school (typical age of students 13 years). Specialized subject teachers teach students also in upper secondary schools (typical age of students 16–19 years).

of chemistry teacher education at the unit in question is to train active, skilled and enthusiastic research-oriented teachers capable of lifelong learning (Aksela 2010). Four bachelor's degree level courses and four master's degree level courses deal with chemistry teaching and learning from four different perspectives (Ibid., p. 87): concepts and phenomena in chemistry and their learning; supporting concept building and interest in chemistry through variety of learning strategies (e.g. inquiry, molecular modelling, informal learning); applied chemistry (e.g. renewable resources) in teaching; and the nature of chemistry and scientific literacy.

During the design and development of the course presented in this thesis, perspectives of nature of science and scientific literacy have been studied mainly on two courses. *Chemistry and Environment* (4 ECTS credits) is a bachelor's degree level course, which provides an introduction to scientific literacy by discussing mainly the societal dimensions of chemical practice and chemistry education. This thesis presents the design and development of a master's degree level course *Chemistry as a Scientific Discipline* (5 ECTS credits), which concentrates on NOS dimensions of scientific literacy.

The design of the course *Chemistry as a Scientific Discipline* began in 2007 and the first implementation of the course was in the fall semester of the same year. The second implementation took place two years later in 2009. This study reports two cycles of design, implementation, and evaluation. Educational design research was utilized as a methodological framework for the design process. An overview of the methodological framework is presented in Chapter 3.

The thesis consists of four interconnected studies (Studies I–IV). The goals, methods, and results of these studies are presented and discussed in Chapter 4. Studies I and II (see Section 4.1) describe how NOS is presented in the national frame curricula and upper secondary school chemistry textbooks. These studies provide a quantitative method for the analysis of representations of NOS in chemistry textbooks, as well as describe the components of domain-specific NOS for chemistry education. The analysis and description of domain-specific NOS were informed by research on the philosophy of chemistry and chemical education. In the design research project, studies were part of the problem analysis, characterizing the challenges, opportunities, and goals of the pre-service chemistry teacher education course on NOS.

Studies III and IV (see Section 4.2) document the design, development, and evaluation of the goals and instructional practices used on the course. The choice of the key ideas to be covered on the course and the challenges of a specific course on NOS for pre-service chemistry teachers are based on the previous descriptions of similar courses, the research on teaching and learning NOS, the research on philosophy of chemistry and chemistry education, and the analysis of chemistry curricula and textbooks. Based on the problem analysis, several design solutions were produced. The evaluations of the practicality and effectiveness of the design solutions are based on the reflective essays and interviews of the pre-service teachers on the course, as well as on the four in-depth interviews of selected participants, carried out a year after they had graduated as qualified teachers.

Discussion and conclusions based on the results of the studies and the research questions for this overview (see Chapter 1) are presented in Chapter 5. The third implementation of the course was carried out in 2011–2012. Although the evaluation of the learning on the course is still underway, some of the changes made to the course on that implementation are also discussed in the final chapter.

3 METHODOLOGICAL FRAMEWORK: EDUCATIONAL DESIGN RESEARCH

Educational design research formed the methodological framework for the research project presented here. It is an approach that seeks solutions to complex educational problems through systematic, iterative and continuing process of design, development, and evaluation of educational practices (see e.g. Plomp 2009). Educational design research is usually carried out in a real world situation and addresses problems for which no clear guidelines for solutions are available (Kelly 2009). Theoretical knowledge and evaluative studies of similar interventions are used as the basis of the design and development of various interventions, which are usually carried out and evaluated in naturalistic settings (Bell et al. 2004).

Design research as an educational methodology emerged in the early 1990s (see Brown 1992; Collins 1992). Although there has been and still is wide variety in the approaches, scales of research, and research processes used in educational design research,[9] researchers also agree on a number of key characteristics (Plomp 2009). According to the summary of van den Akker et al. (2006), design research is: (i) *interventionist*, as it aims at designing an intervention in a real world setting; (ii) *iterative*, as it is based on cycles of problem analysis, development, and evaluation; (iii) *process oriented*, as the focus is on understanding and improving the interventions; (iv) *utility oriented*, as the merit is at least in part measured by it's practicality in real contexts; and (v) *theory oriented*, as the design is based upon theoretical propositions, and results contribute to theory building or testing. Discussion on how these characteristics are realized in the research project documented here is presented in Chapter 5.

Educational design research approach has been informed by practices of other design sciences, such as architecture and engineering. Although education design research seeks answers to educational problems and seeks to build our understanding of learning, educational design research is more solution oriented than traditional educational research (see e.g. Plomp 2009). In design process, the problem and the solution often emerge together and the problem may not be fully understood, before there is a solution to illustrate it (Lawson 1997). This is also the case with many problems in educational setting. The challenges faced by educators implementing novel practices or approaches can be described as wicked problems in a sense described by Rittel and Webber (1977) and elaborated by Buchanan (1992). Wicked problems are defined as ill-defined problems in

[9] Design oriented approaches include among others *design experiments* (Brown 1992), *didactical engineering* (Artique 1994), *educational reconstruction* (Duit et al. 2005), and *formative interventions* (Engeström 2011).

which the solutions seem frustrating and potentially unattainable. Kelly (2009, p. 76) describes following characteristics of wicked problems in educational setting, which characterize also the problems related to the production of intervention presented in this thesis:

- Content knowledge to be learned is new or being discovered even by the experts.
- Teachers' knowledge and skills are unsatisfactory.
- How to teach the content is unclear.
- Instructional materials are poor or not available.
- Educational researchers' knowledge of the content and instructional strategies is poor.
- Complex societal, policy or political factors may negatively affect progress.

As systematic study of the design and development of educational interventions design research is especially suitable for tackling such complex and ill-defined problems.

There are numerous descriptions of design process, providing sequences of distinct activities occurring in identifiably and logical order. Psychologist, architect, and design theorist Bryan Lawson (1997) describes three activities involved in a design process: analysis, synthesis, and appraisal. *Analysis* is involved in looking for patterns, breaking down the problem to its components, and exploring of relationships between the components. *Synthesis* on the other hand is involved in the opposite: it involves the combination of separate elements in order to form a coherent whole and to generate a solution for the problem at hand. Although Lawson (1989, 1997) describes scientists as preferring a problem-focused strategy emphasizing analysis and architects preferring a solutions-focuses strategy emphasizing synthesis, all design and research involve both activities. The third activity *appraisal* is interested in evaluating the created solution against the objectives identified. Although the design process is sometimes divided into distinct sequences of analytical problem definition, synthetic problem solution and evaluation of solutions, in the actual design process, the activities rarely follow each other in a predictable or identifiable order (see Buchanan 1992; Lawson 1997). Lawson (1997) describes the design process "as a negotiation between problem and solution through the three activities of analysis, synthesis and evaluation" (Ibid., p. 47).

According to Kelly et al. (2008) traditional educational research often emphasizes an analytical stance and favors: (i) convergence of observations and methods with a priori stances, (ii) tendency not to pursue tangential or emergent phenomena, (iii) proclivity to devalue context, and (iv) valuing researcher's assumed objective stance over the subjective stance of "subjects". They argue, that in contrast to such stance, educational design research favors a more "fluid, empathetic, dynamic, environment responsive, future-oriented and solutions focused nature of design" (Ibid., p. 5). This is also the case with the design research project documented here.

Educational design research is also closely related to research in instructional design (see e.g. Reiser 2012). The origins of instructional design can be dated back to World War II, when psychologists began to develop analysis, design, and evaluation procedures for military training. After the war, psychologists responsible for military training programs continued working on instructional design procedures in other settings. In the 1960s and 1970s, educational researchers began to describe various instructional design models. Most of these instructional system design models were based on B. F. Skinner's (1954) and Robert Mager's (1962) research on programmed learning, Benjamin Bloom's (1956) taxonomy of cognitive learning, as well as Robert Gagné's (1965) description of five domains of learning outcomes and the events of instruction for promoting them. In the 1980s and 1990s the interest in instructional design remained strong on fields such as business, industry, and military training. During those decades, some pioneering efforts of implementing instructional design models to school and higher education were also made (Reiser 2012). From the 1990s the growing interest in constructivism, as a collection of views about learning and instruction, has had a significant impact on instructional design practices (see Hannafin and Hill 2012, Reiser 2012). Contrasting with the previous instructional design approaches, constructivistic design practices

Table 1 *Design frameworks and practices (Hannafin and Hill 2012).*

	Traditional instructional design	Constructivistic design
Epistemological perspective	Positivism	Relativism
	Knowledge exists independent of the learner	Knowledge is constructed by the learner
	There is an absolute truth	Truth is contextual
Design framework	Knowledge engineered externally	Knowledge constructed internally
	Transfer knowledge from outside to inside the learner	Guide the learner in constructing knowledge
	Arrange conditions to promote specific goals	Provide a rich context for negotiation and meaning construction
Design practices	Directed	Learner-centered
	Teacher directing; learner receiving	Teacher facilitating; learner controlling
	Predeterminated goals and objectives	Learning goals negotiated
	Activites, materials, and assessment teacher-driven	Activities, materials, and assessment context-driven and individually constructed
	Products given to teacher for assessment	Products shared and reflected on collectively

emphasize individuals as active learners controlling their own learning process, as well as collective and contextual construction of knowledge (see Table 1).

Although there are several design models used in instructional design and educational design research, most of them are based on the traditional ADDIE model with five phases: (i) *analysis* of the goals and objectives of the project as well as the learner characteristics: (ii) *design* of the learning activities to meet the goals identified, (iii) *development* of learning materials for the learning activities being implemented, (iv) *implementation* of the designed activities, and (v) *evaluation* of the success of the implementation including both formative assessment for altering and enhancing the design as well as summative assessment of meeting the goals of the project (see e.g. Kelly et al. 2008; Gustafson and Branch 2012).

The results of the research project documented here are discussed using a design research model by Edelson (2002).[10] The model describes three separate but intertwined elements of design research: (i) the *problem analysis* characterizes the goals and opportunities of the design as well as the challenges and constraints it has, (ii) the *design solution* describes the resulting design, and (iii) the *design procedure* specifies the processes involved in the development of a design. Corresponding with these elements, design research produces three types of theories: (i) *domain theories* are generalizations of some portion of the problem analysis, (ii) *design frameworks* describe the characteristics of successful design solutions, and (iii) *design methodologies* provide guidelines for the design process. Discussion on the results of the studies presented in Chapter 5 is arranged according to these three types of theories produced.

Besides the design research approach described here, multiple research methods and approaches were used. Methods used during the problem analysis (Studies I and II), and in evaluating the design solutions and design procedures (Studies III and IV) are discussed in more detail in the following chapter.

[10] The Unit of Chemistry Teacher Education has produced several master's thesis' and two academic dissertations' utilizing Edelsons educational design research model, see Aksela (2005), Pernaa (2010). The co-operative construction of design solutions by a team of designers used by the unit is discussed in more detail in Vesterinen et al. (2012).

4 DESCRIPTION OF THE STUDIES

The goal of the problem analysis was to describe the challenges, constraints and opportunities of a specific course on NOS for pre-service chemistry teachers. Identification of the challenges was based on theoretical problem analysis of a previous research on the issue[11] as well as on empirical problem analysis focusing on the challenges of local context of school chemistry teaching. The empirical parts of the problem analysis were reported in two research papers documenting the content analysis of the Nordic national frame curricula (Study I) and upper secondary school chemistry textbooks (Study II). The methods, and results of these studies are presented and discussed in the first section of this chapter (Section 4.1).

The design solutions developed and implemented to address the challenges identified during the problem analysis, as well as the evaluation of the design solutions is presented in Studies III and IV. The methods and results of these studies are presented and discussed in Section 4.2.

4.1 PROBLEM ANALYSIS (STUDIES I AND II)

To get a picture of the external factors (see Fullan and Stigelbauer 1991) influencing the adoption of NOS instruction in Finland, two interconnected studies were carried out.

In Finland, the educational aims for comprehensive and upper secondary school education are defined by the national core curriculum. Study I is a descriptive content analysis of NOS in the chemistry syllabi of the upper secondary school core curriculum. It compares the 'ideas-about-chemistry' presented in Finnish, Norwegian, and Swedish national frame curricula, and analyzes how those ideas relate to the ideas presented in research literature.

Textbooks are important science teaching resources (Ahtineva 2000; Drechsler and Schmidt 2005; Abd-El-Khalick at al. 2008). As teachers and students often rely on textbooks to organize teaching and learning, textbooks have long been an area of intense interest in educational research (Chiappetta at al. 1991a). Textbooks do not only present conceptual and theoretical knowledge, but also the picture of the cultural, methodological and epistemological aspects of the scientific discipline in question. Study II investigated the picture of chemistry as a scientific discipline presented in

[11] Previous research on the issue utilized in the theoretical problem analysis included for example several evaluative studies on the impact of history and philosophy of science courses on preservice teachers views of NOS, instructional planning and classroom practice: see e.g. Abd-El-Khalick (2005) Abd-El-Khalick and Lederman (2000b), Akerson et al. (2000), Bell et al. (2000), Niaz (2009). Results of the initial problem analysis as well as the results of the subsequent rounds of problem analysis are discussed in more detail in Subsection 5.1.2.

Finnish and Swedish upper secondary school chemistry textbooks.[12]

4.1.1 METHOD

Both studies utilized content analysis methodology. In Study I the inductive content analysis of Finnish, Norvegian and Swedish national frame curricula was carried out in three phases described by Huberman and Miles (1994):

1. The data was reduced by selecting the statements related to the issue.
2. The selected data was organized and assembled to form categories. The formed categories were constantly evaluated to views presented in the research.
3. The results were discussed by comparing the three national frame curricula with each other and the ideas derived from previous research.

In the second phase nine categories were formed and then organized into two themes connecting the related issues. The first theme collected categories related to the epistemological dimensions of chemical reseach and thus focused on the philosophical perspectives of scientific practice. The theme contained five categories: (i) *chemistry as research into the characteristics, structure and function of substances*, (ii) *models as a means of explaining chemical phenomena*, (iii) *the tentative nature of chemical knowledge*, (iv) *the way theories and models affect experimental research*, and (v) *experimental research as a step-by-step–procedure*. The second theme collected categories related to the social and societal character of chemistry and emphasized ethics and external sociology of science (see Ziman 1984). The theme contained four categories: (i) *the societal importance of the applications of chemistry*, (ii) *the impact of chemical knowledge on our culture and worldview*, (iii) *the chemical knowledge as a basis for societal and ethic decisions and discussion*, and (iv) *chemists making ethical decisions*. The validity of categories formed was evaluated by two

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[12] A number of other domain specific chemistry textbook analyses have been made. Most of them have analyzed textbooks published in the USA. Several studies by Mansoor Niaz and his group have analyzed NOS aspects in textbooks with respect to handling specific chemistry topics. The analyzed topics include: oil drop experiment (Niaz 2000a), kinetic molecular theory of gases (Niaz 2000b), laws of definite and multiple proportions (Niaz 2001a), covalent bond (Niaz 2001b), atomic structure (Rodríguez & Niaz 2002), periodic table (Brito et al. 2005), and quantum numbers (Niaz and Fernández 2008). Abd-El-Khalick et al. (2008) has also investigated handling of NOS in chapters related to 'the scientific method', atomic structure, kinetic molecular theory, and gas laws using a general NOS framework. Niaz and Maza (2011) utilized similar framework in their analysis of introductory chapter of chemistry textbooks. Unlike the procedures used in previous studies, the procedure used in Study II enables the quantitative analysis of whole textbook and it utilizes a domain specific framework of analysis for NOS aspects.

researchers. To support the conclusions, a number of direct quotes from the data were also provided.

In Study II a more quantitative strategy of content analysis was utilized. Two Finnish and three Swedish series of upper secondary school chemistry textbooks were chosen for content analysis based on their market share. The books were then analyzed in two rounds. The analysis on the first round was based on analytical framework and procedure described and validated by Chiappetta et al. (1991a, b, c, 1993). According to the guidelines described in the procedure, a 10 % random sample of the textbook was chosen for the first round of analysis. In defining the units of analysis for this first round of analysis, the criteria defined by Chiapetta et al. (1991a) were followed. The units to analyze within the textbooks included: complete paragraphs; questions; figures with captions; tables and pictures with captions; marginal comments or definitions; and complete steps of a laboratory or hands-on activity. The units not analyzed in the first round of analysis included: paragraphs that have begun or ended on another page; figures without captions; pages with frontispiece, even if accompanied by a caption or one or more paragraphs; pages with fewer than two analyzable units; and goals and objective statements.

All applicable units of analysis within the sample were analyzed using the four main themes of scientific literacy described by Chiapetta et al. (1991a): (i) *the knowledge of science*; (ii) *the investigative nature of science*; (iii) *science as a way of thinking*; and (iv) *interaction of science, technology and society*.

Two researchers analyzed the sample independently. After calculating the inter-rater agreement, differences were discussed and final markings negotiated. The distribution of emphasis on each dimension was presented as a proportion of analyzed units categorized to each theme.

The framework validated in the first round of analysis was used to select the units of analysis for the second round of analysis. The theme of *science as a way of thinking* was chosen for a closer inspection. The textbooks were read carefully and the units of analysis belonging to the theme were identified and marked. In defining the units of analysis, the same criteria were used as in the first round. To cover all the analyzed units in the textbooks, also the paragraphs that have begun or ended on another page as well as pages with frontispiece or with fewer than two analyzable units were included in the analysis.

The marked units were analyzed using an analytical framework based on previous descriptions of central aspects of NOS (e.g. Abd-El-Khalick et al. 2008), and domain-specific research on philosophy of chemistry and chemical education (e.g. Erduran and Scerri 2002). The framework was refined in several rounds of organizing and assembling of units to the initial categories, reformulating categories, and comparing the formed categories to views presented in the research. The analytical framework included following dimensions of NOS: (i) *tentative nature of scientific knowledge*, (ii) *empirical nature of scientific research*, (iii) *use of models and modelling in chemistry*, (iv) *inferential nature of chemistry*, (v) *technological products of chemistry*, (vi) *instrumentation in chemistry*, and (vii) *social and societal dimensions of chemistry* (for description of the categories, see Subsection 5.1.2).

Unlike in previous studies evaluating the representations of NOS in textbooks (e.g. Abd-El-Khalick et al. 2008), the study did not evaluate, how right/informed or wrong/uninformed these representations might have been, but rather focused on the amount of discussion on each topic. The dimensions of NOS were considered more like features of science to be elaborated and discussed about, rather than group of claims to be learned and memorized (see Clough 2007; Matthews 2012). The amount of discussion on each dimension was reported as a number of measured units. The analysis includes both explicit and implicit discussion of NOS dimensions. However, research on the relative impact of implicit versus explicit approaches to addressing NOS shows that implicit approaches are not as effective as explicit reflective approaches (see e.g. Abd-El-Khalick and Lederman, 2000a, Khishfe & Abd-El-Khalick, 2002). Thus, notice was paid also on the amount of explicit discussion on each dimension.

To evaluate the reliability of the procedure and framework of analysis two people analyzed the material independently and inter-rater agreement was calculated. One of the coders was the first author of the article and the other one was a PhD-student not connected with the research project. Inter-rater agreement for each textbook was measured using Cohen's kappa coefficient, which takes into account the agreement occurring by chance (Cohen 1960). The higher the inter-rater agreement: the higher the value of coefficient, with the maximum possible value of 1. Kappa value of 0 indicates that the agreement between the raters is most probably due to chance.

To use the Cohen's kappa coefficient units to be categorized must be independent from each other, the categories have to be mutually exclusive (nominal scale) and the raters have to work independently. These conditions were met.

Cohen's kappa coefficient κ is calculated using the following formula.

(1) $$\kappa = \frac{p_0 - p_e}{1 - p_e}$$

Where p_0 is the observed level of agreement and p_e is the expected level of agreement. Expected level of agreement can be calculated using a table of inter-rater agreement (see Table 2 and the following formulae).

(2) $$p_0 = p_{11} + p_{22}$$

(3) $$p_e = p_{A1}p_{B1} + p_{A2}p_{B2}$$

Table 2 Inter-rater agreement between raters A and B.

		Rater A		
		1	2	Total
Rater B	1	p_{11}	p_{21}	p_{B1}
	2	p_{12}	p_{22}	p_{B2}
	Total	p_{A1}	p_{A2}	1

The Cohen's kappa coefficient for inter-rater reliability of analysis for each textbook series was calculated using *IBM SPSS Statistics 19*. In both frameworks of analysis, calculations resulted in a moderate to high-level inter-rater agreement with kappa statistic ranging from .65 to .87. Based on the inter-rater agreement, the procedure and frameworks of analysis presented in the study were a reliable way of assessing the emphasis given to the domain specific dimensions of NOS.

4.1.2 RESULTS

Comparing the results of the content analysis of Finnish, Norwegian, and Swedish national frame curricula presented in Study I, there were number of NOS related topics not explicitly mentioned in the Finnish core curriculum. The topics not mentioned in the Finnish core curriculum include *the tentative nature of science* and *the impact of chemical knowledge on our culture and worldview*.

Several themes not explicitly mentioned in any of the national frame curricula were also recognized. Themes not mentioned include: (i) *the limits of the chemical models and theories*, (ii) *the relationship between chemistry and other natural sciences*, iii) *the importance of creativity in chemical research*, iv) *the concepts of evidence in science texts*, v) *the social nature of chemical research*, and vi) *chemistry as a technological practice*.

According to the results of the first round of analysis of Study II, only a small fraction of analyzed Finnish and Swedish upper secondary school chemistry textbooks focus on discussing NOS issues. Less than 5% of all analyzed units discussed theme *science as a way of thinking* and percentage of emphasis for the theme *interaction of science, technology and society* was also low. Finnish and Swedish upper secondary school chemistry textbooks seem thus overtly focused on *the content of science*.

Based on the second round of analysis of Study II, *the tentative NOS* is the dimension with most emphasis on Finnish and Swedish textbooks. In line with the differences of national core curricula, Swedish textbooks emphasize the tentative dimension of NOS more than Finnish textbooks. On *the empirical NOS* all textbooks provide some descriptions of historical experiments as well as explicit descriptions of a step-to-step procedure for research. This is again in line with the national core curricula as both Finnish and Swedish core curricula present simplistic step-to-step description of research process in chemistry.

The model-based and *inferential NOS* are discussed in more detail in only one Finnish textbook series. The other textbooks give only examples of these dimensions, while discussing topics like development of atomic models, the creation of the periodic table of elements and models of chemical bonding.

All analyzed textbooks provide historical and contemporary examples of *the technological products of chemistry*, and *role of instrumentation in chemical research*, but explicit discussion on the issues is almost nonexistent. Although both development of instruments, and synthesis of new substances are integral parts of nature of chemistry, role of instrumentation is not explicitly discussed in any of the analyzed textbooks and only one textbook discusses explicitly *technological products of chemistry*.

Although examples of the *social and societal dimensions* of chemistry can be found from every analyzed textbook, explicit discussion is missing. The examples provided in the textbooks are mainly vignettes of historical scientists.

4.1.3 DISCUSSION

Based on the results from Studies I and II, it is suggested, that to provide teachers with a sufficiently wide variety of examples to discuss the different dimensions of NOS, changes to the national core curricula and Finnish matriculation exam are needed.

The domain-specific dimensions of NOS were formulated based on the research on philosophy of chemistry and chemistry education. Some of the dimensions were similar enough for comparisons with previous studies utilizing more general frameworks of analysis. Comparison of the proportion of textbooks discussing four common dimensions in the study and two other studies (Abd-El-Khalick et al. 2008; Niaz and Maza 2011) is presented in Table 3. As seen from the table, *tentative* and *empirical NOS* are the most common dimensions to be discussed in chemistry textbooks.

According to the analyses (see Table 3) *social and societal aspects of NOS* are rarely explicitly discussed in chemistry textbooks both in Nordic countries and in USA. This and lack of discussion on creative aspects of chemistry can lead to highly idealized portrayal of scientists and scientific practice, in which science is seen as highly systematic, asocial and uncreative activity. Such a portrayal might alienate especially students, who appreciate creativity and curiosity. Lack of examples of living, non-western and women scientists also supports stereotypical view of chemistry and chemists.

Of the new dimensions of NOS based on the research on philosophy of chemistry and chemistry education, *the use of models and modelling* in Swedish upper secondary school chemistry textbooks has previously been studied in the context of acid-base models by Drechsler and Schmidt (2005). In line with the results of their study, also the Study II concludes that textbooks rarely explicitly discuss the role of models and modelling in chemistry and the limitations of different models.

Table 3 *Percentage of textbooks discussing selected NOS dimensions*

NOS dimension	Implicit representation of the dimension (%) / Explicit description of the dimension (%)		
	Finnish and Swedish textbooks (Study II)	Selected chapters in textbooks published in USA (Abd-El-Khalick et al. 2008)	Introduction chapter in textbooks published in USA (Niaz and Maza 2011)
Tentative[a]	100 / 80	79 / 14	56 / 17
Empirical[b]	100 / 60	100 / 36	37 / 16
Inferential[c]	100 / 20	86 / 57	15 / 8
Social aspects[d]	100 / 0	50 / 7	8 / 7

[a] Abd-El-Khalick et al. 2008 utilized a scoring rubric which analyzed also the consistency of the representations of each dimension. On this table percentage of textbooks with implicit representation of tentative NOS includes 36% of textbooks scored as naïve or inconsistent.

[b] Niaz and Maza (2011) use following description: "Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, creativity and skepticism".

[c] Niaz and Maza (2011) use following description: "Scientists can interpret the same experimental data differently".

[d] Abd-El-Khalick et al. 2008 report separately "Social dimensions of science" and "Social and cultural embeddedness of science". Niaz and Maza (2011) use following description: "Scientific ideas are affected by their social and historic milieu".

As a part of a larger educational design-research project, the aim of Studies I and II was to provide an overview of the situation in Finnish schools and define the relevant aspects of NOS to be included in the pre-service chemistry teacher education course.[13] The key ideas to be covered on the designed course were based on the domain specific framework produced in these studies (see Study IV). This aspect of the problem analysis is discussed in more detail in Subsection 5.1.2.

4.2 DESIGN PROCEDURE AND SOLUTIONS (STUDIES III AND IV)

To integrate NOS dimensions into their teaching, teachers need sufficient understanding of NOS issues as well as effective instructional practices for NOS instruction (e.g. Abd-El-Khalick and Lederman, 2000a). Based on the initial theoretical problem analysis, following challenges for design of a pre-service chemistry teacher course on NOS were recognized: (i) *need to define the central dimensions of domain-specific NOS for chemistry education* (see

[13] Although, studies about teachers' and students' views about nature of physics has been carried out by Sormunen (1999, 2004, 2008), evaluations about the role of nature of chemistry within the Finnish educational system have not been previously carried out.

Studies I and II); (ii) *pre-service teachers' need for connection to authentic research to prevent dilution of relevance to scientific practice in their understanding of NOS* (see e.g. McComas et al. 1998); (iii) *need for structured opportunities for reflection and discussion to improve pre-service teachers' knowledge of NOS and understanding of the importance of NOS instruction* (see e.g. Abd-El-Khalick and Akerson 2004); and (iv) *lack of suitable teaching materials* (see e.g. Study II; Höttecke and Riess 2009) *as well as pedagogic approaches and strategies to translate NOS understanding into classroom practice* (see e.g. Abd-El-Khalick and Lederman 2000a). The design solutions developed and implemented to address the challenges on the course were described and evaluated in Studies III and IV.

4.2.1 METHOD

The main data sources used in the evaluation of the research group visits presented in Study III were the 15 reflective essays about the research group visits. The essays were collected from 2007 implementation of the course. Inductive content analysis of the essays was again carried out in three phases described by Huberman and Miles (1994):

1. The data was reduced by selecting the statements related philosophical and sociological perspectives on the chemical practice.
2. The statements were organized and assembled first into themes and then into categories. The categorizations were generated in the form of concept maps (see Novak and Govin 1984; Novak 1998) describing the interrelationships among the categories.
3. Conclusions were made by comparing the formed categorizations to the research on interdisciplinary fields of philosophy of chemistry and NOS instruction.

The main data-sources used in the evaluation of design solutions in Study IV were the semi-structured in-depth interviews (see Hirsjärvi and Hurme 2009) of four former course participants a year after their graduation. Interviewing teachers working as qualified chemistry teachers after the course enabled the evaluation of how the participants implemented NOS instruction to the realities of regular classrooms. The data was analyzed utilizing analytical induction (Huberman and Miles 1994; Punch 2005) and summarized in form of a narrative, describing the similarities and differences among the participants' commitment to teach NOS (see Subsection 5.1.1). Conclusions were made by comparing the narrative to the results of previous research on the issue.

To increase the reliability of the evaluation of design solutions, Plomp (2009) suggests using triangulation of data sources. Data used for such triangulation in Studies III and IV included semi-structured group interviews, participants' essays for learning assignments, final exams, and anonymous course feedback. As suggested by Lincoln and Cuba (1985), also member checks were carried out in both studies, by providing participants with the results of the content analysis for comment.

4.2.2 RESULTS

To address the challenges identified during the problem analysis, four corresponding design solutions were designed for the 2007 and 2009 implementations of the course (see Table 4). The design solutions were described and evaluated in two case studies: Study III focused on the reseach group visit asignments and Study IV on the three other design solutions.

Table 4 *Key challenges identified during the problem analysis and corresponding design solutions for each challenge*

Key challenges identified	Design solutions implemented
Need to define the key concepts to be discussed on the course	Description of central dimensions of domain-specific NOS for chemistry education
Need for structured opportunities for reflection and discussion	Teaching cycle with recurring phases of personal and communal reflection
Need for connection to authentic research	Research group visit assignment
Lack of suitable teaching materials and pedagogic approaches and strategies	Collaborative design assignments to produce teaching plans for NOS

It has been argued that a discrete course on NOS might disconnect from science content and thus possibly dilute its relevance (see e.g. McComas et al. 1998). This challenge was acknowledged by arranging research group visits and by engaging practicing chemists in the group discussions. The description and evaluation of this aspect of the course was presented in Study III. The study evaluated how the participants experienced the research group visits and how the pre-service chemistry teachers' interaction with scientists supported them in internalizing understanding of NOS.

According to the results of the study, research group visits provided the participants a context for discussing several domain specific dimensions of NOS created during the problem analysis, especially about the social and societal dimensions of science (see Table 5). However, research group visits were not an all-inclusive context for teaching key ideas-about-science. For some issues, like for discussing the tentative nature of scientific knowledge or the inferential knowledge of scientific knowledge, approaches utilizing history of science might be more suitable.

Study IV presents the development and evaluation of three design solutions: (i) definition of central dimensions of domain-specific NOS for chemistry education, (ii) teaching cycle for explicit and structured opportunities for reflection and discussion, and (iii) design assignments to translate NOS understanding into classroom practice. In addition to presenting the results of the evaluation of design solutions, the study also includes description of the design procedure used on the development of the course.

Table 5 *Domain specific dimensions of NOS (Study II) and issues discussed in the essays about research group visits (Study III)*

Themes discussed in the essays	Issues discussed in the essays	Dimensions of domain-specific NOS
Chemistry as an inquiry	Choices by researchers	Empirical nature of scientific research
	Reseach methods	
	Empirical and computational methods	Use of models and modelling in chemistry
	Research subject	Technological products of chemistry
	Instrumentation	Instrumentation in chemistry
	–	Inferential nature of chemistry
	–	Tentative nature of scientific knowledge
Chemistry as a collaborative effort	Chemistry as a collaborative effort	Social dimensions of chemistry[a]
	Interdisciplinarity	
	Publishing results	
Relationship of chemical research and society	Applications	Societal dimensions of chemistry[a]
	Basic and applied research	
	Financing	

[a] *Social and societal dimensions of chemistry* has here been divided in two parts: *societal dimensions of chemistry* focuses on the internal sociology of science and *societal dimensions of chemistry* focuses on the external sociology of science (see Ziman 1984).

The evaluation presented in Study IV supports a notion, that a domain specific perspective on teaching NOS in the context of chemistry education is needed. NOS courses initial focus should also be on internalizing the importance of developing the understanding of NOS as a valued goal of chemistry education.

Based on the evaluation, the teaching cycle with recurring phases of personal and communal reflection supported internalizing understanding of NOS and transforming the understanding into instruction. The teaching cycle used on the course supported also the iterative development of the course, as each round of review acted as problem analysis in a weekly microcycle of design (see Gravemeijer and Cobb 2006).

The design assignments in which the participants by a collaborative and communal effort developed materials for teaching NOS were practical enough to be implemented. The descriptions of central features of practicality by Doyle and Ponder (1977) were used in the evaluation of the practicality of plans:

1. *Instrumentality*: Innovative teaching practices should be translated to concrete classroom procedures (e.g. teaching plans) rather than abstract principles (e.g. NOS tenets).
2. *Congruence*: There should be congruence between the innovative teaching practices and the teachers' perception of their own situations. The practice should fit in the teachers' way of conducting classroom activities, their self-image, and the classroom setting they are operating in.
3. *Cost*: The ratio between the benefits of the innovative teaching practice and the effort to enact it. Therefore the teaching practices should not demand huge amount of effort from the teachers enacting them.

The results suggested that the possibility of trying out teaching plans for NOS instruction during the course could improve congruence between the innovative teaching practices and the teachers' perception of their own situations (see Doyle and Ponder 1977), and thus support participants' commitment to teach NOS (see Subsection 5.1.1), especially among the less experienced participants.

4.2.3 DISCUSSION

Based on the evidence from Study III, research group visits were an important part of the course and enabled discussion on wide range of NOS issues. The fact that research group visits did not seem like an all-inclusive context for teaching key ideas-about-science, led to using history of science as a context for one of the design assignments on both implementations of the course.

Results of Study IV suggests that one of the critical factors influencing pre-service teacher's commitment to teach NOS (see Subsection 5.1.1) is the possibility to implement NOS instruction during the course. To further develop participants' attitudes, beliefs and skills necessary for teaching NOS, the study suggests using collaborative peer teaching and integrating teaching practice on NOS instruction courses. Based on this conclusion, on 2011–2012 implementation of the course, the focus of the teaching cycle shifted towards collaborative peer teaching, and student teaching was integrated within the course. These changes and their possible ramifications are discussed in more detail in Section 5.2.

5 DISCUSSION AND CONCLUSIONS

Results of this research project are discussed in the five sections. The first section (Section 5.1) focuses on the domain theories, characterizing the possible outcomes and challenges associated with the course. It addresses the questions, “What are the possible outcomes of a chemistry teacher education course on nature of science?” (see Subsection 5.1.1) and “What are the challenges associated with the design of such course?” (see Subsection 5.1.2). Second section (Section 5.2) describes the design framework describing the characteristics of successful design solutions. It focuses on the question, “What are the characteristics of a successful chemistry teacher education course on nature of science?” Third section (Section 5.3) discusses the design methodologies providing guidelines for the design process used on the development of the course and addresses the question, “What are the characteristics of a successful design process for developing a course supporting implementation of innovative new teaching practices?” Final section (Section 5.4) discusses some of the implications of the research project.

5.1 DOMAIN THEORIES

Domain theories are generalizations of problem analysis. In his model of education design research, Edelson (2002) describes two types of domain theories, *outcome theories* and *context theories*. Outcome theories characterize the possible outcomes of the designed intervention, and context theories characterize the challenges associated with the problem at hand. Following subsections discuss both outcome and context theories used and developed during the design research project.

5.1.1 OUTCOME THEORIES

Outcome theories are models of the possible outcomes of the designed intervention. Understanding how implementation could bring forth the desired outcome “is essential to successful design“ (Edelson 2002, p. 113). Overarching goal of the teacher education program in question is to develop pre-service teachers’ pedagogic content knowledge (Aksela 2010). Although some initial characteristics of pedagogical content knowledge for NOS were recognized from the evaluation of learning during the courses (see Study IV), complete description of pedagogical content knowledge for NOS was beyond the scope of the research project documented here. However, as one element of functional pedagogical content knowledge for NOS, describing teachers’ motivation to implement innovative new practices, concept *commitment to teach NOS* was used to describe the desired outcome of the course.

To development of students' understanding of NOS is a long-term process and requires much effort from the teacher (see Study IV). As long-term goals require persistency and willingness to exert effort for achieving them, goals must be perceived as meaningful and worthwhile and teachers must be highly motivated (see Johnson and Johnson 2003). History shows that usually only a small number of teachers will be highly motivated in promoting new innovative teaching practices (see Aikenhead 2006). To create innovators and early adopters (see Rogers 1962) of new educational innovations, there is a need to understand how we can facilitate motivation to implement new approaches, for pre- and in-service teachers alike.

Levis (1935) has argued that all motivation is goal-oriented; only the degree of explicit awareness of the goals underlying the motivations varies. Johnson and Johnson (2003) go even further and see motivation and goals as two sides of the same coin. They define goals as a "desired future state of affairs or outcomes" (Ibid., p. 137) and motivation as the degree of effort committed to achieve goals. They argue that understanding motivation is a key to understanding goal-oriented behavior.

Motivation is a complicated and dynamic process affected by cognitive, affective, and social issues. Self-determination theory, created and developed by Deci and Ryan (1985, 1987, 2000), provides a theoretical model for facilitating motivation. Self-determination theory describes motivation as a continuum of self-determination from *amotivation* (lack of motivation) through four phases of *extrinsic motivation* (*external regulation*, *introjected regulation*, *identified regulation*, *integrated regulation*) to *intrinsic motivation* (see Figure 1). Amotivation is a total lack of intention and motivation. On the other end of the spectrum, intrinsic motivation involves people doing an activity out of their own interest and the spontaneous satisfaction from the activity itself. Extrinsic motivation is somehow controlled by the reasons to engage in the activity.

In self-determination theory, extrinsic motivation is characterized in terms of the degree to which the regulation of the motivation is autonomous (e.g. Deci and Ryan 2000; Gagne and Deci 2005). In *external regulation*, an activity is performed in the hope of reaching a desired result or avoiding an undesired one; motivation is totally initiated and maintained by external contingencies. By internalization, people take in values and beliefs that support the activity, and regulatory attitudes do not require the presence of external contingencies. In *introjected regulation*, a person partakes in the activity to feel worthy, despite not accepting the importance of goals and regulations. In *identified regulation*, a person feels greater autonomy and freedom, as partaking in the activity is congruent with personal goals and values. *Integrated regulation* is the fullest type of internalization, in which the activity is seen as an integral part of sense of self. What differentiates integrated regulation from intrinsic motivation is that the activity is of instrumental importance for personal goals, but not interesting and enjoyable in itself.

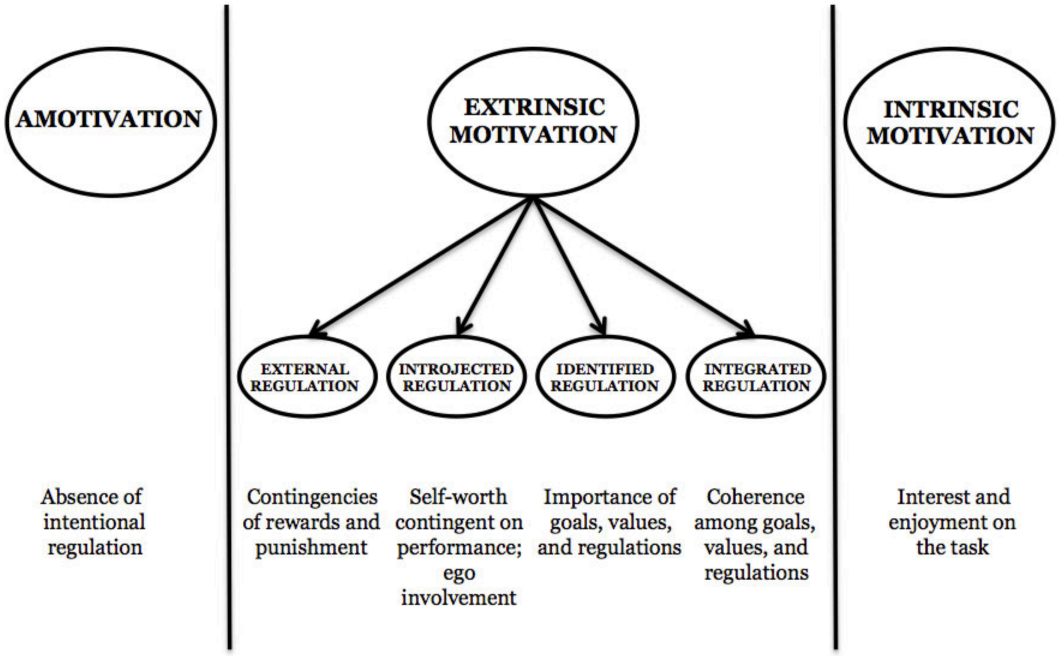

Figure 1 Self-determination continuum from amotivation to intrinsic motivation and the nature of regulation for each (Gagne and Deci, 2005)

Development in the commitment to teach NOS is defined as moving towars a more autonomous regulation of motivation to implement NOS instruction. Such commitment demands coherence among goals and values as well as relevant skills for successfull implementation. Self-determination theory postulates that internalization of self-determination is based on satisfying three basic needs: need for competence, need for relatedness, and need for autonomy (e.g. Deci and Ryan 1987, 2000). The needs act as required nutriments for the internalization of autonomous regulation (Gagne and Deci 2005). The first issue is *competence*. Ryan and Deci (2000) argue that people will adopt goals in which they perceive they have competence. Understanding the goal and having the relevant skills for succeeding in it are the cornerstones of competence. The second issue, *relatedness*, is a sense of belongingness and connectedness to the persons, group, or culture. The final and critical issue in the development of internalization beyond introjected regulation is the need for *autonomy*. Developing a sense of personal responsibility involves having the experience of choice. An autonomous action is one for which the person in question is personally responsible.

Following these three needs, commitment to teach NOS has three dimensions:

1. *Competence for teaching NOS* consists of understanding of NOS and instructional strategies to teach NOS. Gaining experiences of success in teaching NOS is especially important part of self-efficacy

related to such competence.[14]

2. *Relatedness to teaching NOS* consist of compatibility of personal goals and values with teaching NOS as well as support from colleagues and students' response to NOS instruction.
3. *Autonomy in teaching NOS* consist of freedom to decide the content to be taught and teaching strategy to be used. Autonomy is constrained by several factors, such as the demands of the curricula and the expectations of students.

Internalization of a more self-determined type of motivation can be supported in various ways. For example, positive feedback enhances intrinsic motivation by providing satisfaction of the need for competence; providing choice and acknowledging feelings provide satisfaction of the need for autonomy; and feeling understood and gaining appreciation from others provide satisfaction of the need for relatedness (Deci and Ryan 2000; Niemiec and Ryan 2009; Reis et al. 2000; Ryan and Deci 2000). The way needs for competence, related and autonomy were taken into account to support commitment to teach NOS and are discussed in more detail in Section 5.2.

5.1.2 CONTEXT THEORIES

The initial problem analysis provided us with four possible challenges associated with supporting pre-service teachers in internalizing understanding of NOS and in transforming their understanding into NOS instruction (see Section 4.2): (i) the need to define the central dimensions of domain-specific NOS for chemistry education; (ii) the teachers' need for connection to authentic research to prevent dilution of relevance to scientific practice in their understanding of NOS; (iii) the need for structured opportunities for reflection and discussion to improve the teachers' knowledge of NOS and understanding of the importance of NOS instruction; and (iv) the lack of suitable teaching materials and pedagogic approaches and strategies to translate NOS understanding into classroom practice. These challenges functioned as the initial context theory (see Edelson 2002) for the development of solutions.

During the following rounds of evaluation and problem analysis, the

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[14] Perceived self-efficacy is the conviction in ones own effectiveness on a given task (Bandura 1977, 1994). Self-efficacy can also be described as perceived competence and is closely related to motivation (Bandura and Schunk 1981). Self-efficacy has a direct influence on choice of activities and on persistency to work on tasks (Bandura 1977). The perceived self-efficacy is easy to measure e.g. with surveys, and thus has been widely used in educational research focused on three areas: links between self-efficacy beliefs and career choices, correlation of teachers self-efficacy with student achievement, and effect of students' perceived self-efficacy on their motivation and achievement (see Pajares 1997). In terms of self-determination theory, self-efficacy is concerned almost exclusively with competence, and by leaving out other psychological needs "loses the meaningful basis provided by the needs concept for differentiating the processes and contents of goal pursuits" (Deci and Ryan 2000, p. 257).

picture of the challenges developed. Studies III and IV provided new knowledge about challenges associated with implemeting such course. Thus, the context theory associated with the course as well as the design solutions based on the context theory could be refined. The challenges concerning (i) the identification of key concepts and development of learning goals, (ii) providing rich context for meaning construction, and (iii) the construction of learning sequences (see Hannafin and Hill 2012) are presented in the following unnumbered subsections.

Identification of key concepts and development of learning goals

To develop pre-service chemistry teachers' understanding of NOS and skills in NOS instruction, there was a *need for domain specific description on what teaching NOS means in the context of chemistry education*. The key concepts of NOS to be discussed on the course were identified in the description of central dimensions of domain-specific NOS (see Studies I and II). Based on the previous descriptions of central aspects of NOS, domain-specific research on philosophy of chemistry and chemical education, and analysis of local curricula and textbooks, description of seven features characterizing chemistry as a scientific discipline were presented:

1. *Tentative*: Even though some categories of knowledge are more durable, scientific knowledge is never absolute or certain. Models, theories and laws have changed through history and are still subject to change. This tentative nature of scientific knowledge is seen as one of the central elements of nature of science (e.g. Lederman et al. 2002; Osborne et al. 2003; Abd-El-Khalick et al. 2008; Niaz and Maza 2011). Development of historical models and discovery of previously unknown elements are examples of this aspect. The progress of chemistry can be seen not only on the level of changing laws, theories and models, but also on the development of new instruments and synthesis of new substances (e.g. Nye 1993; van Brakel 2000). This aspect is thus closely related with aspects of instrumentation and technological products.
2. *Empirical*: Among experts, there are differing opinions on whether we should stress the common elements of scientific research methods. 'The scientific method' is suggested as one of the central NOS topics by Osborne et al. (2003) and on the other hand seen as a myth by Lederman et al. (2002). For detailed discussion on the differences of the approaches, see Niaz (2008). However, both Osborne et al. (2003) and Lederman et al. (2002) agree that although science is not rigid and uses several methods in creation of scientific knowledge, scientific claims are derived from observations of natural phenomena. Observations about chemical phenomena are often, but not always, obtained through experimentation. This aspect contains discussion about the process of scientific inquiry as well as descriptions of scientific experiments and verification of scientific models through observations.

3. *Model-based*: In the recent decades, the model-based view of science inspired by the ideas of philosophers Nancy D. Cartright (1983) and Ronald N. Giere (1999) among others has provided much insight to the research of science education (see e.g. Gilbert and Boulter 2000). In chemistry, models representing certain aspects of the world are used as a way to explain phenomena (Carpenter 2000). As we move from macroscopic to microscopic and submicroscopic 'realities', the models need more and more idealizations (van Brakel 2000). Hence, chemical models cannot be all-inclusive presentations of the world or faithful copies of reality, and are always level specific and limited in their scope (see Wartofsky 1979; Erduran 2001, Erduran and Scerri 2002). Discussion on the role of models and modelling in chemistry and on the limitations of models are examples of this aspect.
4. *Inferential*: In creation of models, one has to take into account that chemical phenomena happening on submicroscopic level are not directly accessible to senses (e.g. van Brakel 2000). Models in chemistry are thus inferential, in the sense they can only be measured through effects and scientists use creativity in inventing explanations for and descriptions of the phenomena (see Baird 2000; Lederman et al. 2002; Osborne et al. 2003).
5. *Technological products*: Chemistry is not only interested in the properties of molecules, but also in generating new substances and refining the processes of production (Nye 1993). Producing new substances can even be seen as the main activity of chemists during the past 200 years (Schummer 1997; Kovac 2002). Even basic research in chemistry is not only concerned about explaining the world, but also about the manipulation of matter on molecular level. Of the thousands of scientific articles in chemistry published every week, most deal with the creation of new substances (Schummer 1999). New substances are not only the products of the research; they are also the subjects of the research. As 19th century chemist Berthelot pointed out: "Chemistry creates its own subject. This creative ability, similar to an art, is the main feature that distinguishes chemistry from the natural and humanitarian sciences" (as cited in Smit, Bochkov and Caple 1998, p. 28). This dimension is thus closely connected with instrumentation. This dimension includes the discussion on the synthesis of new substances as one of the goals of research as well as historical and contemporary examples of such activity.
6. *Instrumentation*: Direct observation of phenomena usually happen at level unattainable by our perception, and phenomena are accessed through the window of technology, with instruments specially designed towards refining our current scientific models (Hacking 1983). Technology plays a huge role in the process of creating chemical knowledge, as instruments, experimental settings, and objects of research are all created by scientists. New technology drives forward scientific practice. The way chemical research is done has always been and still is transformed by technological development of

instrumentation (Ziman 1984; Baird 2000). Education should take cognizance of this epistemological and cognitive role of instrumentation in empirical science (Tala 2009). Descriptions of development of new instruments and how these instruments have affected research are examples of this aspect.

7. *Social and societal dimensions*: Science is not completely systematic activity. Scientist use variety of approaches and methods in creating scientific knowledge and creation of scientific knowledge is inherently human enterprise. Cooperation and collaboration in the development of scientific knowledge is seen as one of the central 'ideas-about-science' by both Lederman et al. (2002) and Osborne et al. (2003). According to them science as a human enterprise is practiced in the context of larger cultural environment and scientific knowledge is produced in a social setting. The acceptable research methods and results are socially negotiated. As science is not done outside society, also societal needs and support in the form of norms, legislation, and funding affect the way science is practiced. Dividing lines between various scientific disciplines and subareas of science are formed, replaced and removed by time, as scientists borrow concepts from other fields of science, from non-scientific disciplines and from general cultural experience (Benfey 2006). All this holds true for the practice of chemistry.

   However, in describing the larger cultural milieu, in which chemistry is practiced, we have to also acknowledge how closely chemistry as a science is related to chemical industry. As much of the basic research in chemistry has often been and still is use-inspired, the one-dimensional classification of research on the spectrum from pure to applied science is inadequate for chemistry (Kovac 2007). In fact, science and industry seem to have a symbiotic relationship in which chemistry as a science cannot be dissociated from the chemical industry (Aftalion 2001; Laszlo 2006). The cooperation inside and between research groups, review process of scientific journals, scientific conferences and institutions, the division of science into various scientific disciplines, as well as research done for practical or commercial purposes are all aspects of this social and societal dimensions of science.

(Study II, pp. 5–7)

This list of central dimensions of domain-specific NOS should not be seen as conclusive, as there are propably numerous other features of science that could be discussed within secondary school chemistry education (see e.g. Clough 2007; Matthews 2012). Thus the features described should be regarded more as themes of discussion rather than 'the truths' of nature of chemistry to be memorized.

To use their understanding of NOS within their teaching practice, teachers have also a *need for suitable teaching materials and pedagogic approaches and strategies*. This challenge was acknowledged by the collaborative design assignments to produce teaching plans for NOS.

However, there are several local characteristics and external factors constraining the implementation of innovatice new practices such as NOS instruction to novice teachers' day-to-day classroom practice (see Study IV). Thus, during the design process, two other challenges related to development of learning goals for the course surfaced.

Although the description of domain-specific NOS provided the participants "with new perspectives on chemistry, new conceptual framework for thinking and talking about scientific research, and bound the different models and theories of chemistry into a more coherent whole" (Study IV, p. 20), beliefs and values might obstruct the teachers from implementing NOS instruction to their classroom practice. As teachers implement the objectives defined by the national frame curricula, their conceptions about the aims of education are of enormous importance (Hildebrand 2007). Teachers tend to favor approaches that make them feel more comfortable and enhance their identity of self, and resist approaches that cause anxiety or feeling of inadequacy (Barnett and Hodson 2001). Especially novice teachers often spend their first years in a 'survival mode' preoccupied with things such as classroom management (see Russell et al. 2001; Schwartz and Lederman 2002). Hence, novice teachers need to be highly motivated for implementing new practices such as NOS instruction (see also Subsection 5.1.1). During the design of the first implementation of the course a *need to internalize the importance of NOS as a valued instructional outcome* was recognized as the third key challenge of the course.

As also the outside forces of school culture (e.g. school community, curriculum, textbooks) tend to constrain rather than support teachers' efforts to implement change (see e.g. Munby et al. 2000), implementing innovative new practices is usually not easy and requires persistency as well as skills in renegotiating the local school culture (see Study IV). To prepare the pre-service teachers for such external factors constraining the implementation of NOS instruction a *need to challenge the traditional school science culture focusing on transimission of traditional content* was recognized as the fourth key challenge.

Providing rich context for meaning construction

During the initial problem analysis a *need for connection to authentic research to prevent dilution of relevance to scientific practice in teachers understanding of NOS* was recognized as one of the challenges of a specific teacher education course focusing on NOS. Thus, the research group visit assignments have been part of the course from the first implementation. However, they were not an all-inclusive context for discussing key ideas-about-science (see Subsection 4.2.2). The evaluation of the participants' essays about the research group visits presented in Study III suggested that there was a need for a wider context on the NOS issues than the one provided solely by research group visits, especially for a deeper understanding about the tentative nature of science and the interaction between science, technology and society. Thus a *need to contextualize the knowledge about NOS within several authentic and relevant contexts was recognized*.

Construction of learning sequences

During the initial problem analysis, two challenges related to construction of learning sequences were identified: a *need for structured opportunities for reflection and discussion to improve teachers' understanding of NOS*; and a *lack of suitable teaching materials and pedagogic approaches and strategies to translate NOS understanding into classroom practice*. These challenges were acknowledged with utilizing two design solutions: a teaching cycle with recurring phases of personal and communal reflection, and collaborative design assignments to produce teaching plans for NOS. Based on the evaluation of the design solutions presented in Study IV, three new challenges were recognized.

Most reading materials were not written with teachers in mind and did not necessarily link to each other to form a coherent whole (see Study IV). Therefore a *need to provide coherent overview of NOS in chemistry education* was recognized.

Assignments that required the participants to use higher levels of cognitive reasoning, such as critiquing the readings (see Anderson and Krathwohl 2001), did not work well (see Study IV). Thus a *need to find the appropriate level of cognitive reasoning required in the essay assignments* was recognized.

The results of Study IV also suggested that critical factors influencing novice teacher's pedagogical content knowledge related to NOS were the participants previous experience in teaching as well as the possibility to enact NOS instruction during or immediately after the course.

> The possibility to try out the designed teaching plans seemed to support using the plans also after the course, especially among the participants with little previous experience in teaching.
>
> (Study IV, pp. 27–28)

Thus a *need for experiences of teaching NOS while studying about NOS to provide possibilities to contextualize practice within theory and theory within practice* was recognized.

5.2 DESIGN FRAMEWORKS

Design frameworks describe the characteristics of successful design solutions. Although results of design research are usually context bound and do not strive towards context-free statistical generalizations (see Kelly 2006; van den Akker et al. 2006), creation of design frameworks is an attempt to produce generalized and prescriptive descriptions providing transferable knowledge for educational designers seeking solutions to similar wicked educational problems in different contexts (see Edelson 2002).

The production of domain solutions was based on the challenges and desired outcomes recognized during the problem analysis presented in the Section 5.1. The refined descriptions of the key challenges as well as the design solutions implemented are presented in Table 6 and discussed in the following unnumbered subsections.

Table 6 *Refined key challenges and corresponding design solutions for each challenge utilized during the 2011–2012 implementation of the course*

Key challenges identified	Design solutions implemented
Need to define the key concepts to be discussed on the course	Central dimensions of domain-specific NOS for chemistry education
Need to contextualize the knowledge about NOS within authentic and relevant contexts	Providing variety of examples and contexts for discussion, such as the experiences of practicing scientists, historical accounts of scientific and technological development, and contemporary socio-scientific issues
Need to internalize the importance of NOS as a valued instructional outcome	Discussing justifications for the importance of public understanding of science and technology as well as the goal of scientific and technological literacy for all
Need to challenge the traditional school science culture focusing on transimission of traditional content	Discussing on the role of the school science culture in supporting or constraining teaching NOS and renegotiation of the culture
Need for structured opportunities for reflection and discussion	Teaching cycle with recurring phases of personal and communal reflection
Need to translate NOS understanding into classroom practice	Use of collaborative peer teaching and integrating student teaching into the course

Central dimensions of domain-specific NOS for chemistry education

The production of the central dimensions of domain-specific NOS for chemistry education, which informed the choice of key ideas to be discussed on the course, was based on on the previous descriptions of central dimensions of NOS, research on philosophy of chemistry and using philosophy of chemistry in education, as well as to the analysis of local chemistry curricula and textbooks. The description of the dimensions is presented in Subsection 5.1.2.

The analysis of chemistry curricula and textbooks (see Studies I and II) also increased the relevancy of central dimensions, as the results from the analysis were used as readings and the teachers could base their reflections on data on how these dimensions are presented in the current school culture. Thus, the central dimensions of domain-specific NOS were also expected to support the relatedness to teaching NOS (see Subsection 5.1.1). As expected, the key ideas explicitly mentioned in chemistry textbooks and national core curricula were also most often explicitly discussed in the classrooms of teachers who had participated on the course (see Study IV).

A similar description of domain-specific NOS could be formed also for other school subjects such as biology or geography, to support teaching NOS in a more subject specific way.

Providing variety of examples and contexts for discussing NOS

Robust pedagogical content knowledge on NOS demands that teacher has enough contextual knowledge of NOS to lead discussions on NOS issues and to provide good examples (see Hodson 2009). Thus, teacher's competence for teaching NOS (see Subsection 5.1.1) can be supported by providing the teacher with an adequate number of examples to facilitate conversations about NOS in the classroom.

A number of perspectives and contexts for discussion were utilized on the implementations of the course. In addition to the discussions with practicing scientists and research group visits (see Study III), also historical stories about scientific practice and technological development, contemporary sosio-scientific issues, as well as social issues of scientific practice, were used as contexts for discussing NOS issues (see Study IV). The use of socio-scientific issues and social issues of scientific practice, such as gender and equality in science, might be especially important for achieving science education inclusive of all students (see Bianchini and Solomon 2003; Hötecke and Silva 2011). As chemistry as a science is closely related to industry and technology, there is also need to discuss the historical development of technology, as well as the consequences existing and emerging technologies will have upon the society and environment (see Study III).

Discussing the goal of scientific and technological literacy for all

Internalizing the importance of understanding NOS as a valued instructional outcome is an integral part of commitment to teach NOS.

> Even though teachers' conceptions of good teaching and their own teaching is not straightforward, changes in teacher's conceptions of good teaching are sine qua non for changing the teaching approach of the teacher. Thus influencing conceptions of good teaching is prerequisite of implementing new teaching approaches such as NOS instruction. About the importance of intention to teach NOS for the success in NOS instruction see Lederman et al. 2001.
>
> (Study IV, p. 28)

To develop teachers' conceptions about the value of NOS as a valued instructional goal, discussing justifications for the importance of public understanding of science and the goal of scientific for all has been part of the course from the first implementation. This goal is closely connected to pre-service teachers relatedness to teaching NOS, which includes the compatibility of personal goals and values with teaching NOS (see Subsection 5.1.1).

Discussing on the role of the school science culture

Valuing NOS as an instructional aim is also closely related to the self-identity of teachers, as well as to the school science culture they operate in. This is evident especially in the views of one of the interviewed teachers in Study IV.

> Vilma described that she did not feel comfortable discussing philosophical and historical issues and felt more at home with the more absolute "truths" of natural sciences. If science is seen as collection of facts to be transmitted, it is understandable, how one of the pre-service teachers even expressed a fear, that discussion on the epistemological and social dimensions of science would upset students as it had upset him. One reason for this might be, that teaching using NOS and other humanistic perspectives do not align with their self-identity as teachers and thus NOS is seen as somewhat separate from the other aims of science education and (see Aikenhead 2006). The knowledge and skills needed to implement NOS instruction might be in teachers eyes more closely related to the culture of teaching humanities than to the culture of teaching science (see Höttecke and Silva 2011). Keeping this in mind, the traditional view of school science culture can thus be seen also in Vilma's desire to share such responsibility of teaching about NOS with a philosophy teacher.
>
> As the pre-service teachers are usually products of a school science culture with rather traditional beliefs about teaching and learning (see e.g. Bartholomew et al. 2004; Markic et al. 2006; Tsai 2002), it might be unrealistic to expect a course or even the whole pre-service teacher program to totally transform their beliefs and attitudes related to science education. As reflection has a pivotal role in changing such beliefs, more reflection especially on the role of school science culture (see e.g. Munby et al. 2000; Höttecke and Silva 2011) might be needed not just in the few first weeks but rather throughout the whole course.
>
> (Study IV, p. 23)

To transform pre-service teachers' rather traditional beliefs about teaching and learning (see e.g. Bartholomew et al. 2004; Markic et al. 2006; Tsai 2002), the traditional school science culture focusing on transmission of content (see e.g. Aikenhead 2006; Höttecke and Silva 2011) should be problematized. Even though teacher might be committed to implementing new practices such as NOS instruction, the social climate in schools is more likely to constrain an innovative teacher's efforts to implement change than to offer support (see Munby et al., 2000). While implementing new strategies and approaches, teachers will most likely have to be prepared to renegotiate the culture of school science in the school they work in (see Aikenhead, 2006). To support teachers in this, the pre-teachers conceptions of their self-identity as chemistry teachers and the role of school science culture supporting or constraining implementing NOS teaching were discussed thoughout the 2011–2012 implementation of the course. For example, in a role-playing exercises the participants assumed roles of teachers with conflicting views and beliefs working in the same school and acted out negotiations about the objectives of the common school curricula.

Collegial support from a community of like-minded teachers could also support the teachers in developing their self-identities as chemistry teachers and to help them in renegotiating the school culture they operate in (see e.g. Davis 2003). Thus, mentoring programs for novice teachers as well as less formal communities of like-minded teachers might be instrumental in supporting the need for relatedness (see Subsection 5.1.1) among the innovators and early adopters of new practices.

To prepare the novice teachers to be agents of change, there is a need to study furher, what skills are needed in renegotiating the school science culture. More strategies and methods for the task of renegotiating school culture must also be designed and evaluated.

Teaching cycle for explicit and structured opportunities for reflection and discussion

The need for structured opportunities for reflection and discussion was acknowledged by using a learning sequence inspired by the Kolbian learning cycle (Kolb, 1984; Kolb and Fry, 1975). During the teaching cycle used on the course, the participants had the opportunity for personal reflection as well as engaging in active dialogue on each of the themes discussed on the course (see Figure 2).

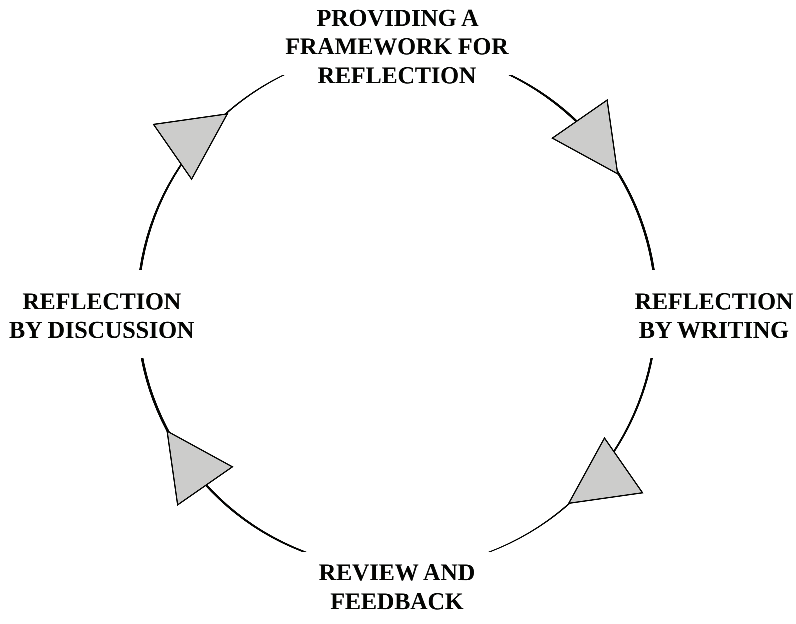

Figure 2 Teaching cycle used on the course (Study IV)

The design and development of the teaching cycle model and evaluation of its practicality are presented in Study IV. Based on the results of this evaluation, the teaching cycle is practical enough to be used on NOS courses. The evaluation also suggested some changes to the teaching cycle to increase its effectiveness. For example, based on the experiences of participants, there was a need to provide more coherent overview of NOS in the readings providing a framework for reflection (see Subsection 5.1.2). Thus a NOS instruction book written for teachers (Hodson 2008) was added to the readings for the 2011–2012 implementation of the course.

The major change concerning the teaching cycle was however the use of collaborative peer teaching, which is discussed in more detail in the following subsection.

Use of collaborative peer teaching and integrating student teaching into the course

The final challenge and design solution discussed here consists of two interrelated challenges and design solutions. To support the translation of understanding of NOS into classroom practice, there is a need for suitable teaching materials and pedagogic approaches and strategies for teaching NOS as well as a need for experiences in teaching NOS to contextualize practice within theory and theory within practice. These needs were acknowledged using two design solutions: collaborative peer teaching, and integrating student teaching (teacher internship) within the course.

A study by Adams and Krockover (1997) defined several concerns that beginning teachers have. Most reported concerns dealt with 'the art and craft of the teaching' such as time management, discipline skills, and presenting the content. Teachers were also concerned about their content knowledge and skills of developing curricula for new courses. Many of these skills are best learned in practice (e.g. Brown et al. 1989; Adams and Krockover 1997). Several student-teaching models have been developed and their merits reported in research, for example pairing of two student-teachers with one cooperating teacher, teaching alongside the cooperating teacher, and teaching according to cooperating teachers plans (Eick et al. 2003). According to the results of these studies, student teaching develop pre-service teachers' confidence in classroom management and presenting the content. As pedagogical content knowledge for innovative new practices such as NOS is a combination of domain specific pedagogical skills and subject knowledge, it is best developed in a reflective process rooted in experiences of implementing such practices (see Brown et al. 1989; van Driel et al. 1998). Thus teaching NOS might be an art best learned through practice.

During the 2011–2012 implementation the participants were given a more active and responsible role in the teaching cycle. Each week a group of pre-service teachers were responsible for designing an essay assignment for the other participants, reviewing the assignments and givin feedback, as well as facilitating the discussions. The instructors assumed a consulting role for each group working as peer teachers. The course instructors had at least three meetings with each group of peer teachers: first meeting was held before publishing the essay assignment, second after the review of the assignments, and third after the group discussion. Thus the participants were not left to their own devices, as the course instructors provided feedback and support to the pre-service teacher throughout the process of designing instruction. Intructors also often provided each group with additional readings during the first two meetings. The last meeting was an evaluative conversation, in which the pre-service teachers and instructors discussed the process. The instructors expected collaborative peer teaching to support the development of pre-sercive teachers conceptions of their role as facilitators of learning, the use of open and dialogic discourse in teaching NOS, and their conceptions of NOS learning goals (see Bartholomew et al. 2004).

The need to translate NOS understanding into classroom practice was acknowledged already in the 2007 and 2009 implementations through two design assignments, in which the participants, by collaborative and communal effort, created and developed ideas and material for teaching NOS. The reasons for the use of design assignments were explained in Study IV:

> The lack of suitable teaching materials and pedagogic approaches is one of the central challenges of implementing NOS issues in teaching (see e.g. Höttecke and Riess 2009, Vesterinen et al. 2011). Providing teaching materials for NOS issues is not by itself sufficient for meaningful professional development of teachers – they have also the need for strategies to translate NOS understanding into classroom practice (Abd-El-Khalick and Lederman 2000a). To enhance their competence in such strategies, teachers should be encouraged to develop their own materials and to revise existing ones (Schwartz and Lederman 2002). This was done through two design assignments in which the participants, by collaborative and communal effort, created and developed ideas and material for teaching NOS.
>
> (Study IV, p. 13)

Although the design of material and teaching strategies played an important part in translating the understanding of NOS into NOS instruction, especially among the less experienced pre-service teachers (see Study IV), a need to implement plans to the practice in the realities of classrooms surfaced.

> The importance of NOS teaching can be internalized by giving teachers the opportunity to experience the significance of NOS within their own practice (Waters-Adams 2006). Getting experiences of success can create an upward spiral, in which attaining success leads to a sense of achievement, which leads to a greater commitment to achieve future goals (Sheldon and Houser-Marko 2001). Such success was seen not only with the experienced teacher Emma, but also with novice teachers such as Sofia, who had the opportunity to try out NOS instruction during the course.
>
> According to the results of this study the opportunity for pre-service

> teachers to carry out their plans enhances commitment to enact NOS instruction. The collaborative peer teaching mentioned above is one opportunity to do this. However, teaching other pre-service teachers is not the same as teaching secondary school students in an authentic school setting. One way to get more authentic experiences would be to arrange teaching practice including NOS instruction. Working alongside more experienced teachers can play an integral role in the adoption of new innovative practices (see e.g. Roth et al. 2004). Authors agree with Abd-El-Khalick et al. (1998) that “pre-service teachers should have planned opportunities to teach the NOS in their internships, as opposed to it being left to chance or to the discretion of mentor teachers” (p. 432).
>
> (Study IV, pp. 25-26)

Thus, during the 2011–2012 implementation of the course, pre-service teachers had the opportunity to implement their plans to practice by teaching upper secondary school students in a regular classroom. Student teaching was carried out at the later half of the course.

As gaining experiences of success in teaching is especially important part of self-efficacy related to teaching NOS, both practices were hoped to support pre-service teachers’ need for competence (see Subsection 5.1.1). Based on the anonymous feedback and initial analysis of interviews from the 2011–2012 implementation, both collaborative peer teaching and integrating student practice within the course were considered as successful changes by the participants. Both design solutions support also instructional principles associated with constructivistism, such as: (i) solving complex and realistic educational problems on how to teach NOS; (ii) working cooperatively to solve those problems; (iii) examining the problems from multiple perspectives (including students’, teachers’, and scientists’ point of view); (iv) taking ownership of learning rather than being a passive recipient of instruction; and (v) becoming aware of their role in the knowledge construction through constant reflection (see Driscoll 2000).

Especially the use of collaborative peer teaching during the 2011–2012 implementation of the course was a move towards more constructivistic design and teaching practices (see Hannafin and Hill 2012). As the instructors assumed a more consulting and facilitating role, the participants had even more responsibility as well as freedom in planning and carrying out the instruction on the course, thus supporting participants’ need for autonomy and relatedness (see Subsection 5.1.1). The participants’ need for autonomy was also supported by the use of self-evaluation in the final assessment. More thorough evaluation about the practicality and effectiveness of the design solutions continues on the fourth implementation of the course in 2012–2013.

5.3 DESIGN METHODOLOGIES

Design methodologies provide guidelines for the design process (Edelson 2002). The design and development of the course documented in this thesis utilized instructional design model based on the traditional ADDIE model (see Section 3). The iterative design cycle used in the development of the course is described in four phases: problem analysis, design (and development), implementation, and evaluation. The design was based on constructivistic learning principles and design activities described in Table 7.

Table 7 Differences in instructional design activities with traditional instructional design and constructional design (see Hannafin and Hill 2012)

	Traditional design activities	Constructivist design activities
Analysis	Content	Context
	Instructional need	Problem described
	Instuctional goal	Key concepts identified
Design (and development)	Instructional objectives	Learning goals
	Task analysis	Identify learning sequences (group and individual)
	Develop instructional materials	Construct learning resources
Implementation	Teacher: conveying, directing	Teacher: consulting, facilitating
	Learner: receiving, acquiring	Learner: directing, controlling
	Focus: objective attainment	Focus: problem-solving
Evaluation	Criterion-referenced assessment	Context-driven evaluation
	What learner knows	How a learner knows
	Knowing that, knowing how	Knowing your way around

Although the design process is described as having distinct phases, each phase included numerous micro-cycles of design, with the continuos activities of analysis, synthesis and evaluation (see Gravemeijer and Cobb 2006; Lawson 1997). The emphases of continuous evaluation used within these micro-cycles of design were based on four criterions for the validity and effectiveness of high quality interventions in educational design research described by Nieveen (2009) (see Figure 3). The four criterions are described in Study IV:

> During the problem analysis and design phases, the evaluation was focused on the relevance (also referred to as content validity) and consistency (also referred to as construct validity) of the problem analysis and design. According to these criteria, the intervention should be based on

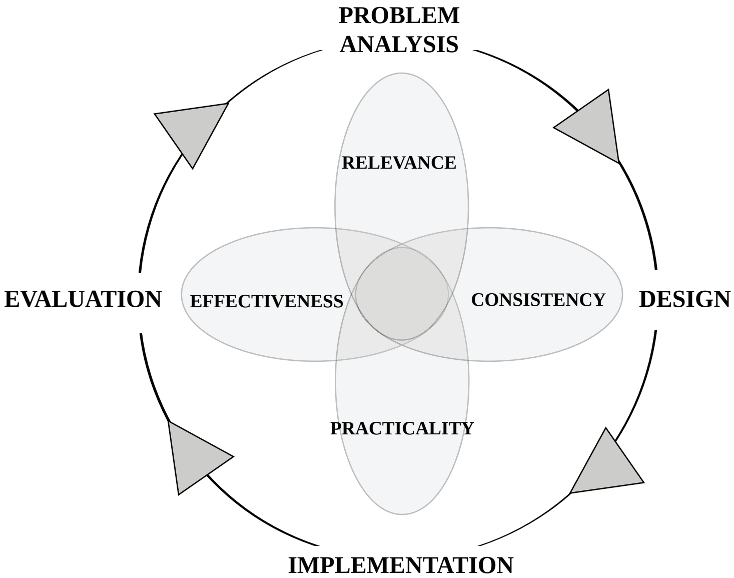

Figure 3 Design cycle used on the design and development of the course and the emphasis of documentation and formative evaluation during the phases (Study IV)

> state-of-the-art scientific knowledge and logically designed. During the implementation of the course the emphasis of evaluation turned to the practicality and effectiveness of the intervention. Practicality means that the intervention is usable in the settings for which it was designed. Effectiveness measures to what extent intervention resulted in desired outcomes.
>
> (Study IV, pp. 4–5)

Also the teaching cycle used on the course, with recurring phases of personal and communal reflection, produced an opportunity for the iterative development of the course, as each round of review acted as problem analysis in a weekly microcycle of design (see Gravemeijer and Cobb 2006). For example, the need to find the appropriate level of cognitive reasoning required in the essay assignments was recognized during the first few rounds of teaching cycle during the first implementation. The instructors thus re-designed the remaining essay assignments to better scaffold the learning (see Study IV).

Van den Akker et al. (2006) described characteristics of a design research study, which were all realized within the design research process documented in this study. The process of design was: (i) *interventionist*, as the course was an intervention in a real world setting; (ii) *iterative*, as the design process progressed in iterative cycles of design, implementation, and evaluation; (iii) *process oriented*, as the focus was on understanding and improving the produced design solutions; (iv) *utility oriented*, as the effectiveness of the course was evaluated by how the learning was implemented in the everyday classroom practive of the participants; and (v) *theory oriented*, as the design contributed to the development of domain theories, design frameworks, and design methodologies.

During the design process understanding about the problems often develop as the design solutions are implemented (see Kelly et al. 2008; Lawson 1997). This was also the case with the project documented in this thesis. Through implementation of the course, instructors found out new challenges as well refined their view of some of the previously recognized challenges. As the problem and the solution emerged together, it became possible to pursue emergent phenomena such as the commitment to teach NOS (see Subsection 5.1.1). Based on this new outcome theory, the evaluation of the second implementation focused on issue not recognized in the initial problem analysis (see Study IV). Although such responsive strategy enables pursuing tangential phenomena, it also presents challenges on gathering of research data, as one cannot know beforehand which data is going to prove usefull. Thus, thorough documentation of each phase of design and implementation was needed (see also Plomp 2009; van den Akker 1999).

McKenney et al. (2006) suggest guidelines for conducting reliable educational design research. In line with these guidelines, studies in this research project utilized several measures were made to address the challenges of educational design research:

- Systematic documentation of the design was carried out throughout the process.
- Contextual frameworks were based on the review of literature and previous interventions were used in the design of the intervention.
- Triangulations of data sources and data collection methods, as well as member checks were used to enhance the reliability and internal validity of the findings.
- Full, context-rich descriptions of the context, design decisions and research results were provided.

The challenges associated with design research, such as the potential bias stemming from the dual roles of the authors as implementers and evaluators, are discussed in more detail in Study IV.

5.4 IMPLICATIONS

The research project documented here, sought to contribute to the understanding about the ways to support implementation of educational innovations such as NOS instruction to classroom practice. The study was carried out in the context of a pre-service chemistry teacher course on NOS instruction designed and implemented by the researchers. The project utilized educational design research approach as the methodological framework for developing the course and producing knowledge about supporting the implementation of NOS instruction.

As a crucial element of pedagogical content knowledge for NOS, concept commitment to teach NOS was described. Based on model of motivation presented in self-determination theory (e.g. Deci and Ryan 1987, 2000), the commitment to teach NOS was defined as an autonomous regulation of motivation to implement NOS instruction. Internalization of the commitment to teach NOS could be supported by satisfying thee needs: need for competence for teaching NOS; need for relatedness to teaching NOS; and need for autonomy in teaching NOS (see Subsection 5.1.1). In the design research process, the concept was utilized as an outcome theory (see Edelson 2002) describing the desired outcome of the course, and each design solution produced during the project was aimed at satisfying at least one of the needs described by the theory (see Section 5.2).

The initial context theory (see Edelson 2002) recognized four challenges associated with supporting pre-service teachers in implementing NOS teaching into their classroom practice: (i) the need to define the central dimensions of domain-specific NOS for chemistry education; (ii) the teachers' need for connection to authentic research to prevent dilution of relevance to scientific practice in their understanding of NOS; (iii) the need for structured opportunities for reflection and discussion to improve teachers' knowledge of NOS and understanding of the importance of NOS instruction; and (iv) the lack of suitable teaching materials and pedagogic approaches and strategies to translate NOS understanding into classroom practice. Based on the challenges recognized in the initial problem analysis, four design solutions were produced. The design and evaluation of these design solutions was presented in Studies III and IV (see Section 4.2).

The evaluation of participants' commitment to teach NOS in Study IV supports the conclusion that implementing new innovative teaching practices to realities of ordinary classrooms through pre-service teacher education is a challenge (see e.g. Aikenhead 2006; Niaz 2009). According to the results of the study, it seems that a mere enthusiasm to implement NOS instruction is not enough, as the outside forces of school culture (e.g. school community, curriculum, textbooks) tend to constrain rather than support novice teachers' efforts to implement such change. However, the results of the study also demonstrate, that a pre-service teacher education course can be successful in producing innovators or early adopters (see Fullan 1993; Rogers 1962) of NOS instruction, and thus might be one of the first steps in injecting NOS instruction into the chemistry curriculum for enhancing comprehensive and upper secondary school students' understanding of NOS and strengthening their scientific literacy.

For open-ended social innovations like the design solutions produced during the project, there are no final designs. As the social situation on every implementation is totally unique and as every student and instructor brings his or her own agency into the situation (see e.g. Engeström 2011), each consecutive round of implementation will be an act of re-design. Based on the experiences of the first two implementations new description of key challenges and corresponding design solutions for each challenge were produced for the 2011–2012 implementation of the course. Description of the characteristics of the seven new or improved design solutions is presented in Section 5.2. These refined key challenges and corresponding design solutions are one of the key results of this study.

The knowledge about the challenges associated with the course as well as the domain frameworks and the design methodology used will be refined also during those consecutive rounds of design. The research project documented in this thesis is also widening its scope towards developing the whole teacher education program, as described in the conclusions of Study IV:

> The research project beginning with this study is now moving on from developing a single NOS course to developing a full pre-service and in-service chemistry teacher education program with the aim of producing teachers with a robust pedagogical content knowledge related to NOS. To be effective, teacher education program should also promote cultural and institutional change to reduce external constraints for teaching NOS. Although this study offers some tools for such progress, more research is still needed both on the elements of pedagogical content knowledge related to NOS as well as on promoting cultural and institutional change within the school science culture. To describe the components of pedagogical content knowledge related to NOS, further studies on the practices of innovators who have successfully implemented NOS instruction are on the way. Although projects like HIPST (History and Philosophy in Science Teaching) have begun addressing the constraints related to teaching NOS (see e.g. Höttecke et al. 2010), there is still need for research based and effective strategies for promoting cultural and institutional change within the school science culture. As the problems associated with promoting cultural and institutional change in education are manifold, there are no self-evident solutions or clear guidelines for solving them. For solutions to such wicked problems (see Rittel and Webber 1973), the educational design research methodology, like the one used in this study, could be used for understanding the issue more deeply and to develop novel solutions.
>
> (Study IV, pp. 28–29)

The results of the research project documented here show, that educational design research methodology can be used to produce transfereable findings about supporting the use of NOS instruction through chemistry teacher education. Thus, design research seems to be a promising methodological framework in seeking solutions for supporting implementations of new innovative teaching practices such as NOS instruction.

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