Chemistry: Content, Context and Choices
Towards students’ higher order problem solving in upper secondary school

Karolina Broman
To my past (my father) and my future (my son)
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Abstract

Chemistry is often claimed to be difficult, irrelevant, and uninteresting to school students. Even students who enjoy doing science often have problems seeing themselves as being scientists. This thesis explores and challenges the negative perception of chemistry by investigating upper secondary students’ views on the subject. Based on students’ ideas for improving chemistry education to make the subject more interesting and meaningful, new learning approaches rooted in context-based learning (CBL) are presented. CBL approaches are applied in several countries to enhance interest, de-emphasise rote learning, and improve students’ higher order thinking.

Students’ views on upper secondary school chemistry classes in combination with their problem-solving strategies and application of chemistry content knowledge when solving context-based chemistry tasks were investigated using a mixed methods approach. Questionnaire responses, written solutions to chemistry problems, classroom observations, and think-aloud interviews with upper secondary students at the Natural Science Programme and with experts working on context-based chemistry tasks were analysed to obtain a general overview and explore specific issues in detail.

Several students were identified who had positive feelings about chemistry, found it interesting, and chose to continue with it beyond the compulsory level, mainly with the aim of future university studies or simply because they enjoyed it. Their suggestions for improving school chemistry by connecting it to everyday life prompted an exploration of CBL approaches. Studies on the cognitive learning outcomes arising from the students’ work on context-based tasks revealed that school chemistry heavily emphasises the recall of memorised facts. However, there is evidence of higher order thinking when students’ problem-solving processes are scaffolded using hints based on the Model of Hierarchical Complexity in Chemistry (MHC-C). In addition, the contextualisation of problems is identified as something that supports learning rather than distracting students.

To conclude, the students in this thesis are interested in chemistry and enjoy chemistry education, and their motives for choosing to study chemistry at the post-compulsory level are related to their aspirations; students’ identity formation is important for their choices. Because students are accustomed to recalling facts and solving chemistry problems that have “one single correct answer”, they find more open problems that demand higher order thinking (e.g. knowledge transfer) unfamiliar and complex, suggesting that such processes should be practiced more often in school chemistry.
## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>CBL</td>
<td>Context-Based Learning</td>
</tr>
<tr>
<td>HOCS</td>
<td>Higher Order Cognitive Skills</td>
</tr>
<tr>
<td>LOCS</td>
<td>Lower Order Cognitive Skills</td>
</tr>
<tr>
<td>MHC-C</td>
<td>Model of Hierarchical Complexity in Chemistry</td>
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<tr>
<td>NSP</td>
<td>Natural Science Programme</td>
</tr>
<tr>
<td>PISA</td>
<td>Programme for International Student Assessment</td>
</tr>
<tr>
<td>RIASEC</td>
<td>Realistic, Investigative, Artistic, Social, Enterprising, and Conventional (model describing personality types)</td>
</tr>
<tr>
<td>ROSE</td>
<td>Relevance Of Science Education</td>
</tr>
<tr>
<td>SSI</td>
<td>Socio-Scientific Issues</td>
</tr>
<tr>
<td>STEM</td>
<td>Science, Technology, Engineering, and Mathematics</td>
</tr>
<tr>
<td>STS</td>
<td>Science-Technology-Society</td>
</tr>
<tr>
<td>VOSTS</td>
<td>Views Of Science-Technology-Society</td>
</tr>
<tr>
<td>ZPD</td>
<td>Zone of Proximal Development</td>
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This thesis is based on the following articles (all published papers are reproduced with the permission of the relevant publisher):

**Paper 1**

**Paper 2**

**Paper 3**

**Paper 4**

**Paper 5**
Sammanfattning på svenska

Kemi är ett skolämne som generellt anses vara både svårt, irrelevant och ointressant för ungdomar. Trots att det ändå finns ungdomar som uppskattar naturvetenskap i allmänhet och kemi i synnerhet, har de ofta problem att se sig själva som naturvetare eller kemister. Denna avhandling undersöker och ifrågasätter den negativa bilden av kemiämnet genom att till en början studera gymnasieelevers syn på kemi. Med utgångspunkt från naturvetarelevens förslag för att förbättra kemiundervisningen och göra ämnet mer intressant och meningsfullt, anknyter avhandlingen därefter till kontextbaserad kemi. Kontextbaserade kurser används i flera länder för att öka elevernas intresse, minska fokuseringen på utantillkunskaper och utveckla elevernas mer avancerade tänkande; med andra ord med målet att uppnå ett meningsfullt lärande. Vid kontextbaserade angreppssätt utgår man från ett sammanhang (kontexten), ofta något personligt eller samhälleligt, som ska vara relevant och intressant. Från dessa kontexter koncentreras därefter undervisningen på de ämnes kunskaper man behöver ha för att förstå sammanhanget (s.k. need-to-know).

Syftet med avhandlingen är att undersöka naturvetarelevens syn på gymnasiekemin, både deras intresse för ämnet och deras skäl att välja det naturvetenskapliga programmet på gymnasiet, samt elevernas problemlösningsförmåga och användande av ämneskunskaper när de löser kontextbaserade kemiuppgifter. Skälet att studera naturvetarelever på gymnasiet är att dessa elever uppfattas som möjliga framtida naturvetare eftersom de själva har valt naturvetenskaplig inriktning efter den obligatoriska grundskolan. Med hjälp av olika metoder (enkäter, klassrumsobservationer, skriftliga lösningar till kemiuppgifter och intervjuer med både elever och experter som löser kemiuppgifter) har analyser genomförts för att dels får en allmän överblick, dels för att utforska specifika delar i detalj både gällande kognitiva och affektiva aspekter av lärande.

Resultaten visar att flertalet elever har en positiv inställning till kemi, många tycker att ämnet är intressant och har valt att fortsätta läsa kemi efter den obligatoriska grundskolan främst med målet att studera vidare på universitetsnivå, men också eftersom de specifikt uppskattar kemi. Gymnasieeleverna lyfter fram lärarna som viktiga och lärarstyrda kemilektioner anses positivet, speciellt om lärarna är strukturerade i sin undervisning. Ett vanligt skäl till att välja naturvetenskapsprogrammet är också att man aktivt väljer utbildning med utgångspunkt från vilken skola man vill gå på, något som i denna avhandling tolkas som ett identitetsskapande. Elevernas förslag för att förbättra skolkemin genom att
anknyta kemin till vardagen låg till grund för avhandlingens fortsatta inriktning mot kontextbaserade angreppssätt.


Sammanfattningsvis konstateras att svenska elever på naturvetenskapsprogrammet är intresserade av kemi och uppskattar kemiundervisningen, speciellt om kemin knyts till vardagen och att lärarna har en tydlig struktur i sin undervisning. Elevernas skäl att välja fortsatta kemistudier efter den obligatoriska grundskolan kan knytas till deras utbildningssträvan men också att elevers identitetsskapande är viktigt för deras gymnasieval. Med hjälp av kontextbaserade angreppssätt kan kemiundervisningen göras mer intressant och relevant samtidigt som elevernas problemlösningsförmåga kan utvecklas. När eleverna möter mer öppna frågor som kräver förklaringar och resonemang är de ovan vid detta och uppfattar uppgifterna komplicerade, samtidigt som de uppskattar denna typ av uppgifter eftersom de uppfattas relevanta och intressanta. Slutsatsen blir att elevernas förmåga till problemlösning av öppna frågor som både kräver faktakunskaper men också förklaringar och resonemang måste tränas ofta inom ramen för skolans kemi för att utveckla elevernas meningsfulla lärande.
Introduction

This thesis is rooted in my experiences as a teacher of chemistry at the upper secondary level and as a teacher educator. It has also been influenced by several thoughts and ideas about school chemistry encountered while working as a chemistry teacher, both in school and at the university level. In 2008, a seminal critical reflection on science education in Europe was presented by an influential group of science education researchers (Osborne & Dillon, 2008). As a novice doctoral student with a background in teaching, several statements and recommendations made in this report either resonated with or contradicted my experiences and have profoundly influenced this work. One of the report’s premises is that school science curricula emphasise factual knowledge presented as a series of fragmented concepts, and that students are therefore never provided with a coherent understanding that ties all the things they learn together into a broader picture. In school, chemistry is often introduced in a historical way; chemistry textbooks extensively discuss scientists such as Berzelius, Mendeleev, Bohr and Scheele (and sometimes also female researchers from the past) and their discoveries about the structure of the world. The world, built of matter, is described in detail, and students are taught many facts about atoms and molecules. They are supposed to read and memorise these facts, and demonstrate their recall of this factual knowledge during written exams. However, I was not convinced that this fact-oriented teaching process and the treatment of chemistry as something historical and old was effective for making students interested in the subject. While factual knowledge is undeniably important, it is not by itself sufficient for meaningful learning. The concept of meaningful learning plays a central role in this thesis and is elaborated at length in the background section.

To illustrate this general picture of school chemistry, Osborne and Dillon (2008) likened the students’ situation to that of passengers on a train who cannot look outside or see their destination; the only person who knows where they are heading is the train driver, i.e. the teacher. School science builds on foundational knowledge; in chemistry, the foundation is the structure of the atom, the smallest unit of matter, and “the bigger picture only unfolds for those who stay the course to the end” (Osborne & Dillon, 2008, p. 15). The report does not blame teachers for the adoption of this approach, and takes pains to emphasise the importance of competent teachers. Instead Osborne and Dillon highlight how the system of assessment adopted in many European countries “encourages rote and performance learning rather than mastery learning for understanding” (Osborne & Dillon, 2008, p. 15). Teachers at the compulsory level are
confronted by two distinct goals – to train future scientists and teach future non-scientists – and the tension between these goals often prompts them to “teach for the test.” It is therefore important to consider the impact of assessment when exploring chemistry education. The report’s main conclusion is that students should be encouraged to engage in higher order thinking about the subject, for example by constructing arguments, posing questions, and establishing relationships.

Although the critical reflections report focuses on cognitive factors, it also discusses several affective aspects. For example, it notes that the Relevance of Science Education (ROSE) study identified a negative correlation of 0.92 between students’ attitudes towards school science and the Human Development Index of their country, together with a decreasing interest in science among students after the age of 14. A gender issue is also noted, with the content of school science courses being considered excessively male-oriented (Osborne & Dillon, 2008). These affective results stood in contrast to my own experiences as a teacher, which motivated me to investigate them in more detail. Another enlightening statement that has influenced this thesis is the report’s claim that the problem is not that students are uninterested in science, “but rather that the perceived values associated with science and technology do not match the values of contemporary youth” (Osborne & Dillon, 2008, p. 17). The perception of adolescence as a time for identity formation and making choices about one’s future suggests a need to focus on questions about who students want to be rather than what they want to do. Consequently, a significant portion of the work presented in this thesis deals with students’ choices in relation to their interests and self-identity; it is assumed that an individual’s decision to pursue a career in chemistry is linked to their personal values and must be understood within that context.

From this seminal report, several projects have followed. Jorde and Dillon (2012) discuss multiple EU-funded projects that have highlighted important issues in Science, Technology, Engineering and Mathematics (STEM) education and identified potential solutions. However, they also assert the need for more multi-country research projects in order to develop our understanding of how best to improve science education. One possible hypothesis for the decreasing interest in STEM among older students is that something happens at the upper secondary level that drives the students away from studying science (and chemistry in particular) at university. This, together with my positive experiences as a chemistry teacher in upper secondary school, prompted me to investigate the STEM-related choices and interest of students at the end of their secondary schooling, considering both cognitive and affective factors. Several important educational scholars, e.g.
Bloom and Krathwohl, have argued that it will be necessary to examine issues from both affective and cognitive perspectives in order to properly understand and explain students’ learning outcomes (Fortus, 2014; Moseley et al., 2005). It should be noted that this thesis deals with chemistry education, and every study presented herein was clearly and explicitly focused on school chemistry. Consequently, all of the conclusions relate to chemistry education alone and no attempt is made to generalise them to other science subjects or to make inferences about all upper secondary students. However, the studies’ results do hopefully clarify some aspects of the relationships between learning and teaching in chemistry.

Chemistry education

The term chemistry education can refer to two different things: the chemistry studied in school or at university, which forms the foundation of this work; and a subfield of research within the broader field of science education. Science education is a relatively new area of research; outside the US, the term was not used in reference to an active area of research until 1963 (Fensham, 2004). Before the Sputnik Crisis in 1957, the US was the only country in the world where science education was conceived as an academic discipline. However, in the 1960s, many countries (including Germany, the UK, Canada and Australia) started supporting research in this field. Swedish research on science education began more recently but is developing rapidly.

The Swedish translation of chemistry education (i.e. ‘kemididaktik’) is related to the notion of ‘didactics’, which is regarded by Lijnse (2000) as a widely overlooked dimension of science education. Lijnse discusses the theory-practice gap and claims that “science education research seems to aim primarily for a content-independent meta-position that links closely with general research in education” (Lijnse, 2000, p. 310) and that “the primary aim of (research in) didactics of science is content-specific didactical knowledge, based on developing and justifying exemplary science teaching practices” (Lijnse, 2000, p. 312). As noted above, the contents of this thesis are clearly linked to the practice of school chemistry and so its focus is more accurately described by the Swedish term ‘kemididaktik’ than by ‘chemistry education’. Furthermore, in a recent review on didactics in Europe, Wickman (2014) stresses this term’s dual orientation: didactics refers to both an academic discipline within educational research and teachers’ knowledge bases, as discussed by Shulman (1986). The apparent connection to the German notion of ‘Bildung’ is important because didactics deals with the
transformation of domain-specific knowledge into knowledge for schooling (Duit, Gropengießer, Kattmann, Komorek, & Parchmann, 2012). This thesis focuses on the academic aspects of 'kemididaktik', but it is hoped that the results will also be relevant and useful to working teachers.

Research in science education, which includes studies on chemistry education, is multidisciplinary and interdisciplinary, with connections to disciplines including the history and philosophy of science, pedagogy, psychology, sociology, ethics, anthropology, and the scientific disciplines of chemistry, biology and physics (Dahncke et al., 2001; Duit et al., 2012). This multidisciplinarity has both advantages and disadvantages; it provides opportunities to study teaching and learning from a broader perspective but also introduces complexities and makes it difficult to derive meaningful interpretations. Fensham's (2004) overview of the field's development highlights a number of its different aspects, including science education in relation to language, content, and gender – topics in which there has been an explosive increase in interest over the last 20 years (Lee, Wu, & Tsai, 2009; Lin, Lin, & Tsai, 2014; Teo, Goh, & Yeo, 2014). However, chemistry education research per se has not had much impact in the more prestigious science education journals: over the last 10 years, only 7.7% of the publications in the four most recognised journals described empirical research on chemistry education (Teo et al., 2014). Therefore, the background section draws on findings from general science education research as well as chemistry-specific material.

As is the case for science education in general (e.g. Osborne & Dillon, 2008), the existing body of chemistry education research mainly highlights problems and challenges (de Jong & Taber, 2007, 2014; Gilbert, de Jong, Justi, Treagust, & van Driel, 2003; Gilbert, Justi, van Driel, de Jong, & Treagust, 2004). Students' attitudes towards and interest in chemistry are often reported to be negative (Barmby, Kind, & Jones, 2008; Bennett & Hogarth, 2009; Osborne & Dillon, 2008; Osborne, Simon, & Collins, 2003), and international projects such as PISA indicate that students' knowledge of chemistry content is declining (OECD, 2010, 2013). Moreover, chemistry is perceived to be difficult (Childs & Sheehan, 2009; Gräber, 2011; Smith, 2011) and abstract (Gräber, 2011) portraying a general picture of a subject in crisis. Various explanations for these perceptions have been suggested: Cook et al. (2013) claim that students focus excessively on memorising facts and formulae rather than understanding concepts and developing problem-solving skills, while Cartrette and Mayo (2011) relate students’ difficulties in chemistry to their limited informal everyday everyday experiences with the subject. It is often suggested that connections to daily life are important in making students more interested in science (Aikenhead, 2006). Consequently,
different strategies have been developed to connect chemistry to higher
order thinking and interesting and relevant everyday life areas, e.g. science-
technology-society (STS), socio-scientific issues (SSI) and context-based
learning (CBL) approaches. This thesis largely deals with CBL approaches,
but the relationship to SSI and STS is obvious and will be addressed in the
background section below.

Research on chemistry education has examined several different aspects of
school chemistry, including the importance of practical laboratory work (e.g.
Abrahams, 2009; Hofstein & Lunetta, 2004; Toplis, 2012) and conceptual
learning through models and visualisation (e.g. Gilbert, Reiner, & Nakhleh,
2008; Gilbert & Treagust, 2009; Rundgren, Hirsch, Chang Rundgren, &
Tibell, 2012). In addition, several studies on specific content areas that
students seem to find challenging have explored students’ misconceptions
and difficulties in grasping certain concepts (e.g. Levy Nahum, Mamlok-
Naaman, Hofstein, & Krajcik, 2007; Park & Light, 2009). Consequently,
much of the literature highlights problems and difficulties, identifying
several areas in need of improvement. However, my experience as a
practitioner suggests that the state of post-compulsory chemistry education
in Sweden is less bleak than these studies might suggest. This research
project is thus informed by my positive experiences as a practitioner as well
as the more objective perspective of a researcher. The process of transition
from practitioner to researcher has influenced my work, and is discussed in a
publication that is not included in this thesis (Broman, submitted). My
background in upper secondary and university chemistry teaching motivated
me to investigate students who were at the end of their upper secondary
studies and had chosen to pursue a course of study that included chemistry
at a post-compulsory level. That is to say, students who had already chosen
to study chemistry in more detail than most. The students examined in this
work are thus potential future scientists, and their experiences are used to
inform conclusions about ways in which school chemistry education could be
improved.

Chemistry and scientific literacy

There are undoubtedly many challenges to overcome in science education
(Osborne, 2007); high school students’ reported experiences of school
science reveal a transmissive pedagogy, decontextualised content, and
unnecessary difficulties (Lyons, 2006). Students’ limited interest in science
is often mentioned as a major obstacle for science education in general and
chemistry education in particular. Student attitudes towards chemistry are
negative, at least at the compulsory level (Bennett & Hogarth, 2009; Hampden-Thompson & Bennett, 2013; Osborne et al., 2003). One way to enhance students’ interest in, attitudes to, and motivation to study science has been to develop new teaching methods such as CBL approaches (e.g. Avargil, Herscovitz, & Dori, 2012; Bennett, Lubben, & Hogarth, 2007; Fechner, 2009; Ültay & Calik, 2012). The theoretical background of CBL approaches derives from the framework of scientific literacy and theories of interest, motivation and situated learning (Menthe & Parchmann, 2015; Nentwig, Demuth, Parchmann, Gräsel, & Ralle, 2007). Scientific literacy is a broad and general notion that is important in several learning approaches and has been used to describe and emphasise the objectives of school science (Bybee, McCrae, & Laurie, 2009; Fensham, 2009; Hofstein, Eilks, & Bybee, 2011; Millar, 2006; Sadler & Zeidler, 2009; Wickman, Liberg, & Östman, 2012). To define the notion, Roberts (2007) has described two emphases of scientific literacy, Vision I and II. Vision I highlights the scientific subject matter whereas Vision II focuses on science in everyday life. Vision II has clearly influenced curriculum development for Swedish compulsory education. Conversely, the subject matter focus of Vision I is readily apparent in the approaches adopted at the post-compulsory level. The works of Roberts and Bybee provide a more exhaustive discussion and elaboration of scientific literacy (Bybee et al., 2009; Roberts, 2007; Roberts & Bybee, 2014).

Smith (2010b) critically disputes the opinion that there is a crisis in school science, at least in the British context, questioning the idea that more scientists are needed in today’s society (Smith, 2010a) as claimed by Osborne and Dillon (2008) and Millar and Osborne (1998). This discussion is relatively political. However, the number of students choosing to study chemistry at Swedish universities has declined over the last 20 years. Consequently, the academics’ trade union has predicted that the country will suffer from a shortage of well-educated chemists in the near future (Karlsson, 2014). There are signs that this trend may have reversed in recent years, since there has been a slight increase in the number of students pursuing science-focused post-compulsory upper secondary courses (Swedish National Agency for Education, 2014). However, the reasons for this shift are not clear and several questions about students’ motives for studying chemistry remain to be answered, as noted by Aikenhead (2003) and Mahaffy (2004). A central challenge for educational systems that raises questions about the extent to which educational research can influence the educational-political interface, is that “the research and its outcomes are located within the existing curriculum [...] the teachers are required to teach (and the students to learn) by the educational system in which they work” (Treagust, 2002, p. 34). I therefore want to clearly emphasise my awareness
of myself as a researcher and a former practitioner, i.e. someone who is both an insider and an outsider in the secondary education system. My intention is to examine upper secondary school chemistry education without offering recipes or lectures. Practitioners may consider some of my findings to be obvious or to have been previously established by long experience. However, from a researcher’s perspective it is clear that the presented results must be examined and scrutinised in detail.

**Aim of the thesis**

The aim of this thesis is to explore upper secondary chemistry education by investigating students’ affective responses to their post-compulsory chemistry education and their cognitive learning outcomes when solving context-based chemistry problems. The purpose of studying the affective aspects is to understand the origins of students’ opinions of their chemistry courses, and to characterise their ideas for improving chemistry education. It is important to understand why students choose to study chemistry in order to build up a comprehensive picture of chemistry education and to relate students’ choices to their interests and identities. The results of the affective studies were then used as a basis for investigations into cognitive aspects and students’ problem-solving processes while working on context-based chemistry tasks. The general research questions this thesis seeks to answer are:

1. What are Swedish upper secondary students’ opinions about their school chemistry courses, and what are their suggestions for improving the subject’s teaching? (cf. papers 1 & 2)

2. Why do Swedish upper secondary students choose to study chemistry at the post-compulsory level, and how is this choice related to identity? (cf. paper 2)

3. How do Swedish upper secondary students apply chemistry content knowledge when solving context-based chemistry problems? (cf. papers 3-5)

4. What problem-solving strategies do Swedish upper secondary students apply when solving context-based chemistry problems, and how do their strategies compare to those used by chemistry experts? (cf. paper 4)

More precise and explicit versions of these research questions are presented in papers 1-5.
Background

To investigate school chemistry and understand how students’ perceptions of the subject are related to their learning outcomes, both affective and cognitive aspects of learning must be considered. Understanding the science learning process has been a challenge for science educators and researchers for several decades, and different ways of interpreting the learning progression have been put forward. This thesis aims to explore meaningful learning (as opposed to rote learning) because several researchers have argued that it is important to promote higher order thinking among students rather than focusing heavily or exclusively on memorisation and the recall of factual knowledge in chemistry education. Therefore, this section begins with a historical perspective on learning in general and meaningful learning in particular to show the origins of this thesis’ epistemology. With the epistemological perspective established, more concrete frameworks for studying cognitive and affective aspects of learning are introduced.

Teaching, learning and thinking in a historical perspective

Psychologists such as Ausubel, Bruner, Piaget and Vygotsky have profoundly influenced ideas about learning since the middle of the 20th century (Fensham, 2004). Research on teaching and learning was mainly affected by Jean Piaget and his constructivistic view (Driver & Easley, 1978; Moseley et al., 2005; Scott, Asoko, & Leach, 2007), and most cognitive science education research has built on his stage theory together with Vygotsky’s sociocultural theories on learning (Mortimer & Scott, 2003; Scott et al., 2007). A vast amount of research has scrutinised the constructivist view in which learning is seen as both an individual construction and a social process of communication with others (Cakir, 2008; Mortimer & Scott, 2003).

In 1956, the legendary educational psychologist, Benjamin Bloom, created a taxonomy featuring three domains that influence learning: the cognitive, the affective and the psychomotor (Bloom, 1956). This taxonomy has informed much subsequent educational research and the practical work of teachers and curricula developers. It has also been revised (Anderson & Krathwohl, 2001), and applied in different learning contexts (e.g. Pungente & Badger, 2003). Bloom’s taxonomy relates learning and teaching to thinking, and Moseley et al. (2005) have summarised frameworks for thinking into a handbook for teaching and learning, useful here as a way to depict possible
frameworks or taxonomies for analysing the learning process. The definition for thinking applied here is broad but highlights several of the aspects studied:

the word ‘thinking’, particularly in educational contexts, is usually used to mean a consciously goal-directed process, such as remembering, forming concepts, planning what to do and say, imagining situations, reasoning, solving problems, considering options, making decisions and judgments, and generating new perspectives (Moseley et al., 2005, p. 12).

The process-words mentioned, e.g. remembering, reasoning and problem solving will in this thesis be analysed in terms of the cognitive and affective domains with an aim to move towards students’ higher order thinking. Thinking is operationalised into chemical thinking using Sevian and Talanquer’s (2014) definition, which describes chemical thinking “as the development and application of chemical knowledge and practices with the main intent of analyzing, synthesizing, and transforming matter for practical purposes” (Sevian & Talanquer, 2014, p. 11).

In the beginning of the science education research era, students’ own construction of knowledge was central. Students’ understandings of different concepts in a range of different content areas were examined and their preconceptions, misconceptions and alternative frameworks were explored (Ausubel, Novak, & Hanesian, 1968; Driver & Easley, 1978). Relating to Piaget’s stage theory regarding younger students, and Ausubel et al.’s (1968) theories regarding adolescent learning, Driver and Easley (1978) focused on how concepts could be taught, for instance the relationship between students’ age and the order of the concepts presented. These early science education studies were followed by several others that examined students’ as well as teachers’ understanding of concepts central to the physical sciences. Duit (2009) has summarised this constructivist research on students’ and teachers’ ideas about science in a bibliography that covers approximately 8400 different research projects, demonstrating the depth and width of this research area. Students’ applications of chemistry concepts are explored in papers 3, 4 and 5 of this thesis.

Over time, science education research has paid more attention to factors other than the individual’s own construction of knowledge. In particular, the relationship between the individual and his/her social surroundings has been highlighted in the so-called post-constructivistic paradigm (Mortimer & Scott, 2003), which emphasises the importance of language (Lemke, 1990; Wellington & Osborne, 2001) and especially argumentation (Simon, Erduran, & Osborne, 2006; von Aufschnaiter, Erduran, Osborne, & Simon, 2008) as well as interpersonal relationships (Leach & Scott, 2008; Moseley...
et al., 2005). Furthermore, the notion of a ‘zone of proximal development’ (ZPD) that was introduced with Vygotsky’s socio-cultural perspective has led to the idea that teachers should help students to engage in higher level thinking, which is often reported to be difficult to achieve without structured assistance. This assistance from the teacher with the aim for higher order thinking was the starting point for the research on cognitive factors in this thesis. Bruner and colleagues introduced the notion of ‘scaffolding’, a form of cognitive apprenticeship whereby the teacher tutors the student in problem solving by structuring their learning conditions in a way that provides the support required to complete a task (Wood, Bruner, & Ross, 1976). Problem solving and scaffolding are discussed more extensively later on in this chapter. The combination of the individual construction of knowledge and the social perspective makes the learning process complex to understand but also justifies its study.

In this thesis, upper secondary chemistry is investigated from the students’ point of view by analysing both the affective and cognitive domains of learning. The studies focus on students’ opinions of their chemistry education as well as their content knowledge and learning outcomes, so the following sections first discuss the cognitive domain of learning and the relationship between rote and meaningful learning, followed by the affective domain.

**Cognitive domain of learning**

As mentioned earlier, Bloom’s (1956) taxonomy of educational objectives has been the basis of several subsequent frameworks for analysing learning processes. In Sweden, Bloom’s ideas can be regarded as the foundations of both the syllabus and the curricula that were in use when the empirical data presented in this thesis were collected (Swedish National Agency for Education, 2000). Moreover, a previous study demonstrated that Bloom’s taxonomy is useful for analysing Swedish upper secondary chemistry because there was a clear alignment between the standards and the assessment of the chemistry courses (Näsström & Henriksson, 2008). These findings motivated the selection of Bloom’s taxonomy as a starting point when searching for more concrete taxonomies or frameworks to support the analysis of the empirical data gathered in this work.
**Rote vs. meaningful learning**

Benjamin Bloom’s hierarchical idea of enhancing complexity stems from Piaget’s stage model. Many scholars have since developed both authors’ ideas further. However, the stage model mainly concerns younger children whereas this thesis examines upper secondary school students. Consequently, the works of Ausubel et al.’s (1968) on learning, and particularly their distinction between rote and meaningful learning, has also been influential. Ausubel et al.’s theory has been questioned by claiming that meaningful and rote learning are just different points on a continuum rather than discrete categories of learning (Grove & Bretz, 2012). Groove and Bretz (2012) investigated organic chemistry to determine why students find this topic difficult, highlighting the apparent need for perceived relevance and meta-cognitive awareness to make students actively choose to learn in a meaningful way by seeking connections rather than focusing on recall and rote memorisation. Whether meaningful and rote learning genuinely represent discrete categories or are just points on a continuum, the dichotomy has been useful in understanding and explaining the results obtained in this work.

Ausubel et al. (1968) claimed that meaningful learning requires relevant prior knowledge, meaningful tasks and learning settings and it is therefore, important to introduce learning in a way that accounts for the learner’s existing knowledge, taking into account the complexity of the new learning and the learner’s cognitive development. Ausubel and colleagues emphasised the importance of the teacher in this process, and asserted that teacher-directed learning is more effective than learning by discovery. Their argument was that student-centred methods can result in uncorrected errors and misconceptions, leading to meaningless rote learning. They therefore concluded by suggesting that teachers should scaffold their students’ thinking and guide them to meaningful learning. Teacher-centred approaches like this have been advocated in recent years by authors such as Bailey (2008). However, the student-centred/teacher-centred dichotomy has been challenged by emphasising the clear advantages of student-centred approaches and by stressing that students should not simply be regarded as passive receivers. Mortimer and Scott (2003) analysed dialogues in science classrooms by scrutinising interactions between teachers and students and the way in which they convey meaning making and learning. Both student-centred and teacher-centred approaches have strengths and weaknesses, but the need for a competent teacher to guide students towards meaningful learning and scaffold their thinking has not been questioned (Osborne & Dillon, 2008). In Sweden there has been a general shift of working methods since the 1980s such that teachers today often act as mentors who guide
students in their learning; “Swedish students thus spend less time being directly instructed by their teachers than do students in other EU and OECD countries on average” (Lundahl & Olofsson, 2014, p. 26). Teachers’ working methods and student-centred/teacher-centred approaches are discussed in papers 1 and 2 of this thesis.

**Meaningful learning - a goal to strive for**

The three requirements for meaningful learning stated by Ausubel and colleagues, i.e. relevant prior knowledge, meaningful tasks and learning settings, have been developed further by authors such as Chin and Brown (2000, 2002). They emphasise that students’ prior knowledge has to connect and intertwine with the disciplinary knowledge; otherwise the learning will be reduced to mere rote learning. By relating to argumentation, von Aufschnaiter et al. (2008) discuss the influence of prior knowledge on students’ cognitive processes by stating that “any attempt to develop students’ knowledge through argumentation must be related to students’ prior knowledge” (von Aufschnaiter et al., 2008, p. 127). To observe students’ prior knowledge, Chin and Brown (2000, 2002) assert the importance of asking questions in the learning process; meaningful learning is based on student-generated questions. This kind of question-posing has been investigated by Herscovitz et al. (2012), who exposed students to a metacognitive tool for posing complex questions and developing reading strategies aimed at understanding adapted scientific articles. Students need to control their learning process, which is possible when higher order thinking and metacognition are promoted and lower order skills such as rote memorisation are de-emphasised. Students’ and teachers’ conversations and question-posing have also been analysed to find ways of explicitly encouraging students to formulate questions on their own and express their ideas through reflective discussions (van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001). This focus on student-generated questions arising from guided discussions, lectures or peer collaboration, has been used to develop students’ conceptual understanding, mainly by clarifying the meaning of subject matter concepts and monitoring subsequent student discussions. Therefore, the questions asked by both the students and the interviewer in this work (see papers 4 and 5) were considered to be equally important because they provide a way to discern meaningful learning. Consequently, this work focuses heavily on two factors that have previously been identified as being crucial for the learning process: students’ own questions and teachers’ discussions with the students during classroom discourse (or, in the studies presented herein, the interviewer’s use of questions) to scaffold
student thinking and help students to construct scientific knowledge (Chin, 2007).

The idea of meaningful learning has also been used by Sevian and Talanquer (2014) to highlight the need to reformulate chemistry education based on learning progressions in chemical thinking. That is to say, it is argued that there should be a shift from learning isolated concepts and ideas about chemical substances to focus on higher order chemical thinking and so-called crosscutting disciplinary concepts, i.e. “lenses through which to analyze students’ conceptual understanding of core elements of chemistry knowledge (e.g., chemical bonding, atomic structure)” (Sevian & Talanquer, 2014, p. 14). Learning progressions relate educational research to critical analysis of content knowledge and thus offer more refined ways of thinking about topics. This evident relationship between meaningful learning and higher order chemical thinking is one of the foundations of this work and will be discussed in combination with the empirical data.

Students’ learning progressions are studied within the research field of ‘didactics’ and Wickman (2014) has recently reviewed a range of Swedish projects in this field. Practical epistemologies research embraces sociocultural and pragmatic theories and within this research tradition, the notion of ‘purpose’ is fundamental; “if the students do not understand what the purpose is, they are left guessing what might be important and less important in the situation or trying to remember everything (i.e., rote learning)” (Wickman, 2014, p. 157). The importance of purpose relates clearly to Ausubel et al.’s (1968) requirements for meaningful learning, i.e. meaningful tasks and meaningful learning settings. Moreover, the awareness of content choice in relation to student engagement is highlighted within the practical epistemologies approach: student engagement is expected to result in meaningful learning. Even though this thesis has a student-oriented perspective whereas practical epistemologies research emanates from the teacher’s side, these ideas of purpose and the relevance of content choice have been central in this work.

**Lower vs. higher order thinking**

Bloom’s original taxonomy (Bloom, 1956) and its subsequent revision (Anderson & Krathwohl, 2001) have prompted demands for a paradigm shift in instructional practice away from reliance on the simple transmission of facts in favour of a focus on higher order thinking and problem solving (Simon et al., 2006; Zohar, 2004; Zoller & Levy Nahum, 2012); by using
Ausubel’s terminology, this would correspond to a shift from rote to meaningful learning. Within chemistry education, new frameworks have been elaborated that can be used to analyse students’ higher order thinking.

One framework of specific interest here was developed by Zoller and colleagues (Zoller & Dori, 2002; Zoller & Levy Nahum, 2012; Zoller & Pushkin, 2007; Zoller & Tsaparlis, 1997). This framework divides skills into higher order and lower order cognitive skills (HOCS and LOCS) and highlights those required to support higher order thinking. The first three cognitive processes from Bloom’s taxonomy (i.e. remember, understand, and apply) are defined as LOCS, whereas the last three (i.e. analyse, evaluate, and create) are considered to be HOCS (Zoller & Levy Nahum, 2012). Since the cognitive processes of the original Bloom’s original taxonomy are hierarchical, LOCS are found to be prerequisites of HOCS (Zoller & Tsaparlis, 1997). This clearly stresses the importance of factual knowledge; meaningful learning requires basic factual knowledge. However, factual knowledge alone is not enough to make learning meaningful. The HOCS/LOCS framework does not use Bloom’s process-words; the higher order cognitive skills required for meaningful learning are instead identified as problem solving, question asking, critical thinking and transfer, among others. One apparent difference between Bloom’s hierarchical taxonomy and the HOCS/LOCS approach is that the higher order skills of the latter are not linearly ordered; problem solving, decision making and question asking are considered to be on the same level, all demanding higher order thinking (Levy Nahum, Ben-Chaim, Azaiza, Herskovitz, & Zoller, 2010).

In school, LOCS such as rote memorisation, recall and algorithmic teaching are dominant, leading students to believe that there is always ‘one single correct’ solution to every chemistry task (Bennett, 2008; Leou, Abder, Riordan, & Zoller, 2006). Consequently, Leou et al. (2006) investigated HOCS-centred learning during an in-service course with the aim of promoting the metacognitive development of science teachers and encouraging them to reflect on their own teaching and increase the emphasis on higher order skills in their classrooms. Despite the various limitations of their study (e.g. the short duration of the course, the small number of participants, and the lack of follow-up studies), Leou et al. (2006) highlight the advantages of using teachers’ higher order skills in the classroom as a way of challenging students to develop their own higher order thinking. This result emphasises the aforementioned importance of teachers to enhance students’ learning outcomes.

Another approach that stresses higher order thinking skills has been proposed by Dori and Zohar with colleagues (Dori, Tal, & TsauShu, 2003;
Zohar, 2004; Zohar & Dori, 2003). This approach differs slightly from the HOCS/LOCS framework, primarily in its wording: it focuses on ‘thinking skills’ instead of ‘cognitive skills’, making it possible to apply these frameworks in combination to explicitly study individual higher order skills such as the transfer of content knowledge during problem-solving processes (Dori & Sasson, 2013). Transfer of content knowledge is perceived as a fusion of all other higher order skills, making it the superordinate HOCS (Zoller & Levy Nahum, 2012). Transfer has been studied within educational research for over 100 years (Marton, 2006) and is often defined as the ability to recall knowledge and skills and then apply them in new contexts (Sasson & Dori, 2012). Thus, while factual knowledge is clearly a prerequisite for transfer, the key challenge in this process lies in the application of established knowledge to new situations involving seemingly unrelated topics and disciplines. Several frameworks for the analysis of transfer have been developed such as the theory-founded three-attribute framework proposed by Dori and Sasson (2013). The three attributes examined in their framework are task distance, interdisciplinarity and skill set, which can be used in combination to distinguish between near and far transfer (cf. paper 3). Transfer in the context of chemistry has been investigated by examining sub-skills such as students’ ability to transfer knowledge between the symbolic, macroscopic and microscopic levels (Dori & Kaberman, 2012; Sasson & Dori, 2014), or apply mathematical skills in chemistry (Potgieter, Harding, & Engelbrecht, 2008). This thesis examines transfer within the discipline of chemistry itself – specifically, the application of knowledge concerning chemical bonding in the study of organic chemistry.

**Complexity of content**

A more recent framework derived from Bloom’s ideas that heavily emphasises the complexity of chemistry content is the Model of Hierarchical Complexity in Chemistry (MHC-C), which is outlined in Table 1 (Bernholt & Parchmann, 2011). The MHC-C was developed from a more general educational model (Commons, Trudeau, Stein, Richards, & Krause, 1998) and was initially used to accurately assess item difficulty in chemistry education (Bernholt & Parchmann, 2011). This competence model makes it possible to assess students’ chemistry content knowledge within evidence-based, outcome-oriented educational systems such as the Swedish school system and has proven useful in empirical studies (Bernholt, Neumann, & Nentwig, 2012). It was therefore selected for use in this work as a tool for analysing students’ problem solving during context-based chemistry tasks.
Table 1. The Model of Hierarchical Complexity in Chemistry (from Bernholt & Parchmann, 2011)

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Everyday experiences</td>
<td>Students describe everyday experiences and base their explanations on knowledge from daily life. They give examples for phenomena. They make and verbalize observations.</td>
<td><em>Example:</em> Can you name things that are burnt in everyday life?</td>
</tr>
<tr>
<td>2. Facts</td>
<td>Students provide isolated terms, definitions, and scientific regularities. Relations do not need to be explicated. The answers consist of reproduced facts without further explanations or argumentation patterns.</td>
<td><em>Example:</em> What is required for something to burn?</td>
</tr>
<tr>
<td>3. Processes</td>
<td>Students describe phenomena and processes as a chronological sequence of distinct events or objects. Eventually, they use (mental) models for clarification purposes. The sequences do not only consist of before-after-descriptions, but focus also on the process, e.g. reaction mechanisms.</td>
<td><em>Example:</em> What happens to a combustible material when it burns?</td>
</tr>
<tr>
<td>4. Linear Causality</td>
<td>Students detect, describe, and explain linear cause-effect-relations. They give reasons for the kind and direction of the relation that go beyond simple if-then-descriptions.</td>
<td><em>Example:</em> Where does the soot of a burning candle come from?</td>
</tr>
<tr>
<td>5. Multivariate Interdependencies</td>
<td>Students detect, describe, and explain relations beyond linear relations. They handle several variables, their interplay, and their contribution to complex cause-effect-relations. In case of a combination of several linear relations, students focus on the superposition and the reciprocal influence of the different relations.</td>
<td><em>Example:</em> Can the amount of energy that is released in a combustion process be predicted?</td>
</tr>
</tbody>
</table>

This hierarchical model is proposed to predict the demand of knowledge-related tasks (Bernholt, Eggert, & Kulgemeyer, 2012). In their analysis of such tasks, Bernholt and Parchmann state that “the complexity of a task depends on the explanatory power of the expected argumentation for a successful solution” (Bernholt & Parchmann, 2011, p. 168). A similar approach was used to analyse a set of ordered multiple-choice items by defining five levels of understanding and characterising the learning
progression of pupils through these levels as they studied the structure and composition of matter (Hadenfeldt, Bernholt, Liu, Neumann, & Parchmann, 2013). During this investigation, the participating students’ understanding of core concepts in chemistry was assessed by Rasch analysis. The response options in the multiple-choice item were connected to different levels of understanding, making it possible to determine whether students could answer the items correctly and to characterise incorrect responses in terms of naïve concepts, hybrid concepts, simple particle concepts, differentiated particle concepts, and systemic particle concepts (Hadenfeldt et al., 2013). These levels of understanding are evidently related to the MHC-C-levels; higher levels of complexity often require higher levels of conceptual understanding. This illustrates how both chemistry tasks as well as students’ responses to the tasks can be analysed according to content complexity. Even though this thesis focuses problem solving of open-ended conceptual chemistry tasks and not multiple-choice items, the MHC-C framework is applied to analyse students’ problem-solving strategies and is regarded as an “amalgam” of HOCS/LOCS and the chemistry syllabus (Swedish National Agency for Education, 2000), which constitutes another obvious foundation for investigations into school chemistry.

**Problem solving in chemistry**

As stated previously, meaningful tasks are required for the promotion of higher order thinking (Ausubel et al., 1968; Chin & Brown, 2000, 2002). This thesis therefore examines problem solving during meaningful tasks in order to characterise the cognitive aspects of students’ learning. Problem solving is a research area that has been studied in chemistry education for several years and is unquestionably important (Black, McCormock, James, & Pedder, 2006; Bodner & Domin, 2000; Bodner & Herron, 2002; Bodner & McMillen, 1986; Zoller & Dori, 2002). John Hayes’ statement that “whenever there is a gap between where you are now and where you want to be, and you don’t know how to find a way to cross that gap, you have a problem” (Hayes, 1989, p. xii) is used to define problems in this work. Problems are contrasted with exercises in which you know what to do after reading the question (Bodner & McMillen, 1986). Because the aim was to study meaningful learning, students were presented with unfamiliar problems to assess their problem-solving strategies.

Hayes (1989) suggested that problem solving involves six steps that were developed from the four initially proposed by Polya 70 years ago. First, you must identify the problem, then represent it, plan a solution, execute the
plan, evaluate the solution, and finally learn from the experience gained by solving the problem. Unlike exercises, which are solved linearly, problems are solved in a cyclic and reflective way (Bodner & Domin, 2000). Assessment in chemistry is clearly related to problem solving, and a strong emphasis on factual knowledge together with algorithmic problems was identified in a study on chemistry learning objectives and exam questions using Bloom's taxonomy (Sanabria-Ríos & Bretz, 2010). Conversely, Overton and Potter (2008, 2011) investigated students’ success in solving and attitudes towards open-ended context-based chemistry problems. Since assessment has an evident impact on teaching leading to the rise of “teaching for the test”, students’ experiences of problem solving are clearly valuable for the assessment of chemistry education. Moreover, “there is also a dissociation between algorithmic and open-ended problem solving, which may well reflect the distinction between lower-order and higher-order cognitive skills” (St Clair-Thompson, Overton, & Bugler, 2012, p. 488). This dissociation was also found in an empirical study on chemistry learning objectives and exam questions, which used Bloom’s taxonomy for analysis and identified a clear link between LOCS and algorithmic tasks on the one hand, and between HOCS and conceptual tasks on the other (Sanabria-Ríos & Bretz, 2010). Open-ended problems and conceptual tasks, defined by Lewis et al. (2011) as problems with a large set of possible correct answers, are therefore used in this work as synonyms for tasks that rely on students’ understanding of chemical concepts rather than the mere recall of facts (Salta & Tzougraki, 2011). This dissociation of tasks has also been discussed in terms of quantitative and qualitative or well-defined and ill-defined problems (Taasoobshirazi & Glynn, 2009).

Chemistry education has a long implicit tradition which holds that “success in solving mathematical problems should indicate mastery of a chemical concept” (Nakhleh & Mitchell, 1993, p. 190) even though this has been questioned lately. An analysis of university level chemistry tasks in England using Bloom’s taxonomy indicated a prevalence of algorithmic tasks (Bennett, 2008) and most previous research has also focused on analysing students solving algorithmic problems (Overton, Potter, & Leng, 2013). However, Overton et al. (2013) studied students solving open-ended chemistry problems, and found that there are three different types of problem solvers: novices, experts, and transitional problem solvers. This finding prompted a comparison of the problem-solving approaches of students (i.e. novices) and experts (i.e. chemistry professors) as presented in paper 4. When analysing university chemistry students’ problem-solving process it was apparent that successful problem-solvers used a consistent approach and applied the information from the non-algorithmic task in an effective way (Cartrette & Bodner, 2010). To solve a problem, both students
and teachers have to be more aware of the students’ prior knowledge and “providing hints to students during, instead of after, the problem-solving process, is most effective at improving their strategic knowledge” (She et al., 2012, p. 751). This result paved the way for a simultaneous analysis of students’ responses and hints given by the interviewer (i.e. me) as a way to explore ways for teachers to scaffold their students during problem-solving exercises.

The teacher’s, tutor’s or interviewer’s role in problem solving was discussed 40 years ago by seminal researchers such as Bruner, using the notion of ‘scaffolding’ (Wood et al., 1976). The scaffolding helps the student to solve a problem or achieve a goal that would have been impossible without assistance, and is thus clearly related to Vygotsky’s ZPD. Wood and Bruner’s initial description of the scaffolding process was based on a study of young children building structures with wood pieces, but several researchers have since refined the concept and applied it in different contexts. One approach to the in-depth analysis of scaffolding uses stepped supporting tools to explore students’ problem-solving strategies together with a teacher’s or interviewer’s hints (Fach, de Boer, & Parchmann, 2007). Fach et al. (2007) analysed students’ problem-solving strategies during stoichiometric tasks by drawing maps of the problem-solving process. This revealed four different supporting tools that teachers can use to scaffold problem solving: (i) giving general instructions on how to address the task, (ii) presenting a solution step-by-step, (iii) giving the student advice on how to perform the steps, and finally (iv) helping students to identify the terms required to solve the task. This thesis investigates both these supporting tools and the solution process itself (cf. paper 5).

A research area adjacent to problem solving is argumentation, which involves the application of central experiences. In their analysis of students’ argumentation and cognitive development, von Aufschnaiter and colleagues emphasise that “we can never ‘really’ know what students have in mind, research relies on sequences of students’ utterances and activities” (von Aufschnaiter et al., 2008, p. 110). Moreover, argumentation research highlights the importance of being aware of students’ prior knowledge, which is clearly consistent with Ausubel’s notion of meaningful learning (Chin & Brown, 2000). Finally, argumentation research shows how the teachers’ oral use of language in the classroom affects the classroom environment to enable student argumentation (Simon et al., 2006). Explicit analysis of students’ and teachers’ argumentation can therefore be used to detect higher order thinking (Zohar & Dori, 2003). The cognitive results obtained in this work are discussed at the end of this thesis in relation to problem solving, argumentation and assessment.
The affective domain of learning

The affective domain of learning can significantly enhance, inhibit or even prevent student learning and is therefore important to consider within educational research. Several scholars have stressed the importance of considering the affective and cognitive domains simultaneously in order to get a more comprehensive picture of the learning process. As mentioned previously, even Bloom and Krathwohl acknowledged that almost every cognitive objective has an affective component, although they considered it too complex to include both domains together in a single framework (Moseley et al., 2005). Fortus (2014) states that “without motivation, interest, positive attitudes and self-efficacy, there can be only limited and curtailed engagement, and without engagement, learning is partial at best” (Fortus, 2014, p. 822). The word ‘affective’ is derived from the Latin word affectus, meaning ‘feelings’, and the domain includes several constructs, such as values, motivation, attitudes, opinions, beliefs and interests (Koballa & Glynn, 2007). The affective domain describes learning objectives that emphasise emotions and feelings. While both are difficult to measure, Scherer (2005) distinguishes emotions from feelings by stating that emotions is a broader term whereas feelings is a more narrow and subjective component. Hence, the term ‘emotion’ will be applied in this section.

This thesis typically applies broad general expressions in preference to clearly defined constructs. For example, the analysis focuses on students’ opinions, ideas, and views about their school chemistry rather than more specific constructs such as attitudes and motivation. This approach was chosen on the basis of Osborne and Collins’ (2001) focus group study on the affective domain, which had the broad premise of investigating students’ views on the role and value of science. The study explored the participating students’ views on science and their reasons for pursuing post-compulsory scientific education, revealing that they found science important and became engaged when learning about topics that they considered to be relevant. They also enjoyed practical laboratory work and appreciated high-quality teaching. However, the students also mentioned some negative factors - they did not always feel sufficiently challenged in science classes and felt that there was too much emphasis on repetitive content in which there was only a single correct answer that had to be learned. In addition to exploring the affective domain, Osborne and Collins also discuss cognitive aspects and claimed that

*it is highly anomalous, that in an age when society increasingly places a premium on the higher order cognitive abilities to retrieve, sort, and sift information, that such curricula continue to place an emphasis on lower order abilities of recall and comprehension of basic concepts (Osborne & Collins, 2001, p. 461).*
Their publication prompted me to investigate whether older students in Sweden hold similar views (cf. papers 1 and 2).

**Attitudes and interest**

The affective construct ‘attitude’ has been studied within science education research for a long time (Barmby et al., 2008; Bennett & Hogarth, 2009; Bennett, Rollnick, Green, & White, 2001; George, 2006; Koballa & Glynn, 2007; Ramsden, 1998; Reid, 2011). However, studies on attitude have become less common in recent years and there has been a growing emphasis on other constructs (Koballa & Glynn, 2007). Nevertheless, there are several important lessons to be taken from the literature on attitudes, some of which have been incorporated into this thesis. Like various other affective constructs, attitudes cannot be observed directly but can be expressed in terms of degrees of favour or disfavour (Eagley & Chaiken, 1993). Students’ attitudes towards science in general and chemistry in particular were reviewed 40 years ago by Gardner (1975) and more recently by Osborne et al. (2003) and Simon and Osborne (2010). A unifying conclusion from these reviews is that attitudes towards science are positive among young children but older students’ attitudes become more negative with age. Reid (2011) presents additional key findings related to attitudes, highlighting for instance the importance of the teacher, that boys and girls are equally interested in science but not in the same areas, and the importance of an explicit career potential. The evident close relationship between attitudes and interest makes it crucial to consider them together when analysing students’ affective responses, although this position has been challenged (e.g. Christidou, 2011). While Fortus (2014) notes that a person might hold a positive attitude about something without being interested in it, it is generally the case that people have positive attitudes about things that interest them. To further complicate the position, Tytler (2014) discusses the notion of attitudes as an umbrella term; “attitudes such as interest, motivation, enjoyment, curiosity, and confidence [...] they are interrelated” (Tytler, 2014, p. 85), whereas Reid (2011) has summarised key findings derived by treating attitude as a construct in its own right, on the basis of research in social psychology. This ambiguity in the definition of the attitudinal construct contributed to the decision to avoid its use in this thesis. The first two exploratory papers of this thesis therefore focused on students’ ‘opinions’ and ‘views’ rather than attitudes, mainly because of my insecurity with these affective constructs during the early stages of my postgraduate studies. The decision was made in accordance with Bennett et al.’s (2001) explanation for focusing on students’ views in the large scale
VOSTS-study investigating students’ views on science-technology-society (VOSTS), in other words, that this thesis only describes students’ views about a more limited area. However, insights from attitude research underpinned the preliminary analysis of the empirical data presented in papers 1 and 2.

As mentioned above, interest is an affective construct that is sometimes taken to be almost a synonym of attitudes and sometimes treated as a construct in its own right (Krapp & Prenzel, 2011). Interest has been investigated for a long time, and various interest frameworks have been developed (cf. Hidi & Reeninger, 2006; Häussler, Hoffman, Langeheine, Rost, & Sievers, 1998; Krapp & Prenzel, 2011). However, there have been several publications on interest in major science education journals that have made no use of interest frameworks, relying instead on intuition-based instruments that have no theoretical support (Fortus, 2014). Interest is primarily conceptualised as a relationship between an individual and a topic, object or activity; in other words, it is content-specific (Häussler et al., 1998). Moreover, interest is characterised by positive emotional experiences and feelings of personal relevance whereas attitudes are supposed to derive from a non-personal viewpoint (Krapp & Prenzel, 2011). When exploring the meaning of interest, Krapp and Prenzel stress that “interest cannot be equated with ‘enjoyment while learning’. Enjoyment can occur for many reasons, and interest is only one of these” (Krapp & Prenzel, 2011, p. 30). While historical interest studies tended to focus on attention, curiosity or intrinsic motivation, the current consensus is that the interest construct is multidimensional and must be described using both cognitive and emotional variables (Krapp & Prenzel, 2011). Three forms of interest are commonly distinguished; a momentary psychological state, situational interest, and individual interest (Dierks, Höffler, & Parchmann, 2014). Gräber (2011) argues that interest has dual functions in education, first as a requirement for meaningful learning, and second as a teaching goal that promotes lifelong open-mindedness.

The well-established physics IPN-interest study examines three interest dimensions; interest in physics, interest in physics lessons, and out-of-school interest in physics (Häussler et al., 1998). Two similar large-scale questionnaire studies on German students’ interest in chemistry were conducted in 1990 and 2008, featuring items on topics, content, context and activities (Bolte, Streller, & Hofstein, 2013; Gräber, 2011). One intriguing finding from these investigations was that students’ interest in school chemistry increased significantly over the 18 years between the two studies, possibly due to the introduction of CBL approaches in chemistry teaching. This result and these dimensions of interest; i.e. topic, content and context,
served as key starting points in the design of the studies presented in this thesis and the development of the context-based problems that students were asked to solve (cf. paper 5). One topic that clearly stimulated students’ interest in the chemistry study (Gräber, 2011) was soaps and detergents; this finding was exploited directly in the study presented in paper 5.

The RIASEC model (Holland, 1963) is a theoretical framework that is widely used to analyse students’ interest orientations in relation to their educational choices and future vocations. It is based on six personality types (Realistic, Investigative, Artistic, Social, Enterprising, and Conventional), each of which is defined by different affective variables, e.g. attitudes, values and interests (Krapp & Prenzel, 2011). A range of studies have built on the RIASEC model and developed it further, using it to analyse student interest profiles (Dierks et al., 2014) or future occupations (Wille & De Fruyt, 2013). These studies indicated that it is important to distinguish between in-school and out-of-school activities when analysing the impact of different personality types because students’ interest structures differed between the two environments (Dierks et al., 2014). Vock et al. (2013) also show that several students at the end of their upper secondary education have stable interest profiles, which influence their later educational and vocational choices. This study also showed that students who specialised in science during secondary school had more pronounced realistic and investigative traits and weaker artistic, social and enterprising traits. The relationship between educational choices and interests is discussed in paper 2 and more extensively later on in this chapter.

The use of ‘interest’ rather than ‘attitude’ in this work was largely due to pragmatic considerations; questions about interest were assumed to be more explicit and easily interpreted by upper secondary school students than equivalents based on the notion of attitude. This might depend on translation; the Swedish word for interest (“intresse”) was considered to be more precise and straightforward than any alternatives. The word ‘attitude’ was also avoided because it often has negative connotations in everyday usage.

Relevance

Related to interest and attitudes is the notion of ‘relevance’, which has been investigated within the ROSE study (e.g. Jenkins & Nelson, 2005; Jidesjö, Oscarsson, Karlsson, & Strömdahl, 2009; Sjøberg & Schreiner, 2010, 2012) among others. The meaning of ‘relevance’ has been questioned in the same
way as other affective constructs, and Stuckey et al. (2013) state that it is inadequately conceptualised. Nevertheless, science education researchers, teachers, policy-makers and curriculum developers frequently use the term by claiming that students find science in general and chemistry in particular irrelevant. Relevance has been discussed in science education for more than 100 years, largely because of educational reforms that have sought to make learning in school ‘relevant’ to students’ lives and futures. The perceived importance of relevance is readily apparent from its appearance in different curricula, and relevance is a watchword in many CBL approaches (King, 2012; Smith, 2011; van Aalsvoort, 2004a, 2004b). Another similar notion that is often taken to be synonymous with relevance is ‘meaningful’; CBL approaches have been implemented in several western countries with the aim of making chemistry relevant and meaningful (King & Ritchie, 2012).

Relevance is clearly aligned with interest; some researchers take them to mean the same thing while others separate them, unfortunately often without clearly defining their differences (Stuckey et al., 2013). For example, the name of the widely cited ROSE study indicates a focus on relevance but its results are often framed in terms of interest. When defining relevance in the context of their project, Schreiner and Sjøberg (2004) state that they use it as a broad concept but could equally well have used the terms meaningful, motivating, interesting, engaging or important. Similarly, when reviewing research on relevance in science education, Stuckey et al. (2013) assert that the ROSE study is actually investigating student interest. One conclusion of their review is that “relevance in science education is mainly related to the question of whether science education content accurately matches the students’ real or perceived interests [...] good reasons to consider ‘relevance’ and ‘interest’ as consisting of overlapping but non-identical ideas” (Stuckey et al., 2013, p. 9). In addition to being a synonym for student interest, Stuckey et al. (2013) define four types of relevance; (i) relevance as a perception of meaningfulness, (ii) relevance as a synonym for importance or usefulness, (iii) relevance as a real-life effect on the individual and the society, and finally (iv) as a combination of all main categorises. In this thesis, relevance is mainly used as a synonym for student interest and to discuss the perception of meaningfulness (cf. papers 1 and 2). However, this usage is discussed and challenged in the outlook section.

Regardless of whether the ROSE study (Sjøberg & Schreiner, 2012) explores relevance, interest or some other affective construct, it has produced a substantial and important body of data that is referred to extensively when analysing the new results presented herein. Within the context of the ROSE study, 15-year-olds from almost 40 countries have completed a questionnaire featuring items on areas students want to learn more about,
e.g. ‘stars, planets and the Universe’, ‘cloning of animals’ or ‘atoms and molecules’. The Swedish ROSE study has explored student interest profiles and related these profiles to students’ upper secondary educational choices, particularly their decisions relating to post-compulsory chemistry studies (Oskarsson & Karlsson, 2011). A factor analysis identified ten different student interest profiles among upper secondary students, one of which (the ‘Risk-factor’, which reflects an interest in explosive chemicals and chemical weapons) clearly correlates with the decision to pursue post-compulsory education in science within the Natural Science Programme (NSP), i.e. the upper secondary programme investigated here. This relationship between interest and choice prompted an investigation into students’ educational choices.

**Educational choices and post-compulsory chemistry**

Students choose areas of study after their compulsory schooling based on both cognitive and affective factors. In Sweden during the period when the data for this study were collected, students had to first choose one of 17 national programmes and then choose which school they wanted to attend because Sweden has a “free school choice” system whereby students of all ages can decide whether they wish to attend a public or a free-of-charge private school (i.e. an independent school), and whether they want to go to a school close to where they live or not. This system was implemented on the basis of a political decision and is intended to reduce segregation, although its justification has been strongly questioned by researchers, the media and the general public (e.g. Swedish Research Council, 2009; Englund, 2014). Furthermore, Lundahl and Olofsson (2014) have shown that this marketization via free school choice and the establishment of independent schools has made each individual student entirely responsible for their own educational decisions and future career. Given the strong emphasis on individual choice, it is very important to understand both the cognitive and affective factors that motivate students to study post-compulsory chemistry within the NSP. Moreover, as mentioned in the introduction, students’ educational choices are strongly linked to their self-identity and values (Osborne & Dillon, 2008), and will be discussed accordingly. Vock et al. (2013) suggest that choice is guided by students’ interests, which is why both factors are considered in paper 2. Based on their studies of Swedish upper secondary students within the NSP, Anderhag et al. (2013) claim that it is important to analyse students’ choices with reference to the questions ‘who are you?’ and ‘who do you want to be?’ rather than focusing exclusively on students’ interest in or enjoyment of science. Several science education
researchers emphasise the pivotal role of identity in students’ educational choices (Archer et al., 2010; Bennett, Lubben, & Hampden-Thompson, 2013; Bøe, Henriksen, Lyons, & Schreiner, 2011; Holmegaard, Ulriksen, & Madsen, 2014; Schreiner & Sjøberg, 2007; Tytler, 2014). Researchers discuss whether identity is something you have, something that is given or taken, or something that changes from situation to situation, and identity is today understood as discursively and contextually produced as well as relational (Archer et al., 2010; Holmegaard, Madsen, & Ulriksen, 2014). The importance of identity can be illustrated by a statement from the ROSE-study; “one’s identity is no longer perceived as something that is handed out or given, but rather something one has to choose and develop by oneself” (Schreiner & Sjøberg, 2007, p. 4). The processes by which students establish their identities in society and in school therefore merit careful investigation.

Within the tradition of situated learning, the theoretical perspective from which the CBL approach emanates, Lave and Wenger (1991) argue that learning in itself also involves identity construction. It has been argued that two key issues must be addressed to encourage more students to choose scientific careers: “the need to increase awareness of career options in the sciences; and the provision of a diversity of role models with which students can identify, in terms of the personal, human possibilities opened up by an education in the sciences” (Tytler & Osborne, 2012, p. 616). Role models have been discussed by Bøe et al. (2011), who stressed the absence of role models in science, especially for girls. By role models, they mean mentors or individuals with whom the student has a personal connection (e.g. parents, teachers, peers, student counsellors) who can help young people to make their choices. The need for role models is discussed in papers 1 and 2.

Besides listening to students who have or will choose science, it is also valuable to investigate students leaving their science studies (Korpershoek, Kuyper, Bosker, & van der Werf, 2012). By analysing students’ attitudes and influence of significant others, the aim was to understand why students who are qualified for science-oriented higher education studies, do not choose this even though previous interest in secondary science education. Students claim they choose the educational option that best fits their attitudes, and that there is few role models, especially female, influencing their choice. One other central point mentioned by the non-choosing students is that persuasive efforts like a one-day visit to the university usually result in temporary rather than long-term changes (Korpershoek et al., 2012). A Danish study on dropout rates from university science courses (Ulriksen, Madsen, & Holmegaard, 2010) highlighted pronounced differences between science education at the upper secondary and university levels, which complicates the transition from one to the other and increases the risk of
dropping out. They also assert the importance of identity as imbedded in the academic culture and emphasise that it encompasses both emotions and actions. An additional and rather disappointing result of their study was that “the students experienced women hired at university as being stressed and the position to be unattractive. Indeed, the female staff almost served as negative role models” (Ulriksen et al., 2010, p. 232).

In a study that explicitly sought to identify factors that influence the decision to pursue a chemistry-related career, Salta et al. (2012) found the nature of school chemistry - irrelevant, difficult and overly focused on rote learning - to be a major problem. In contrast to this result, Holmegaard et al. (2014a) present a different view, stating that some students were attracted by the rigorous and strict nature of science, which made it clear what they were supposed to do. According to Bøe et al. (2011), some students are even attracted to science because of the subjects’ characteristics. These results indicate that students have divergent opinions of the science subjects. However, since school chemistry focuses heavily on rote learning and is taught in a strict way, it is reasonable to suggest that (as suggested in previous sections), teaching approaches should be revised to emphasise meaningful learning and higher order thinking.

The expectancy-value model (Eccles et al., 1983; Eccles, Barber, Updegraff, & O’Brien, 1998) as used by Bøe et al. (2013; 2011) facilitates the analysis of relationships between achievement and interest. The various studies cited in the preceding sections indicate that educational choices are influenced by many complex and overlapping constructs (e.g. motivation, self-efficacy and interest), which makes it difficult to explicitly state the roles of individual affective variables. However, the importance of identity is clear even though, as claimed by Bøe et al., “a real part of the variance observed in young people’s STEM-related choices must be attributed to chance” (Bøe et al., 2011, p. 44). This clear connection of educational and career decisions with the expectancy-value model has been stated by several other researchers (cf. Henriksen, Dillon, & Ryder, 2015; Tytler, 2014) and is applied in paper 2 of this thesis.

To summarise the relationship between identity and student choice, the gap between ‘doing science’ and ‘being a scientist’ delineated by Archer et al. (2010) can be used as a starting point for analysis of the results presented in paper 2. These authors note that even though students generally enjoy science (i.e. they enjoy doing science), most of them do not wish to become scientists. Unquestionably, several parameters influence the possibility to become a ‘real’ scientist, e.g. gender, class, and ethnicity, even though not investigated in this thesis. It would be useful to determine how young people
could be encouraged to see themselves being scientists rather than merely enjoying doing science. This could potentially be achieved in part by linking science education to everyday life so that students can see uses for the science they like to do. A possible way of doing this would be by adopting context-based learning approaches.

### Context-based learning approaches

Context-based learning (CBL) approaches have been introduced in many countries as means of increasing students’ interest and their content knowledge in specific subjects. CBL thus targets both the affective and the cognitive domains of learning (cf. Bennett et al., 2007; de Jong & Taber, 2014). This more unconventional approach towards chemistry emphasises meaningful learning through higher order thinking and increasing student interest, and is presented in this thesis as a potential way of improving chemistry education. Gilbert, Bulte and Pilot (2011) identify five issues related to the cognitive and affective domains of learning that CBL approaches seek to address: the need to reduce curriculum overload, make content knowledge less fragmented, enhance students’ opportunities to transfer knowledge, demonstrate the relevance of science in everyday life, and clarify why students need to study science. Most previous CBL research has analysed innovations at the secondary school level, for instance in the Netherlands (Bulte et al., 2005; Prins, Bulte, van Driel, & Pilot, 2008), Germany (Nentwig et al., 2007; Parchmann et al., 2006), Estonia (Rannikmäe, Teppo, & Holbrook, 2010; Vaino, 2013) and the UK (Barker & Millar, 1999; Bennett & Holman, 2002). However, there are also examples of context-based courses for students at the lower compulsory level (King, Winner, & Ginns, 2011) and at university level (Belt, Leisvik, Hyde, & Overton, 2005; Sumter & Owens, 2011). CBL approaches have been discussed for science in general (Fensham, 2009) and the three core scientific disciplines of chemistry (Bulte, Westbroek, de Jong, & Pilot, 2006; Parchmann et al., 2006), biology (Lewis, 2006; Reiss, 2008) and physics (Taaasoobshirazi & Carr, 2008; Whitelegg & Parry, 1999) separately. Overall, these studies suggest that CBL has positive effects on the affective domain (Fechner, 2009; Yager & Weld, 1999) but its cognitive learning outcomes are more variable (Bennett et al., 2007; King, Bellocchi, & Ritchie, 2008), making it necessary to scrutinise CBL approaches further in order to better understand how these new and unconventional approaches could influence chemistry teaching and learning.
**The notion of context**

Even though CBL approaches have been studied for quite some time (Ramsden, 1997; Schwartz, 1999), different researchers often use slightly different definitions of ‘context’, so it is important to define the meaning of context-based chemistry in this work. The term ‘context’ derives from the Latin word *contextere* and can be interpreted as “the situation within which something exists or happens, and that can help explain it” (Cambridge Dictionary, 2014). Here, context is used as an explanatory variable that helps students to discern the role of chemistry in everyday life situations. Since the notion of context is often broadly defined, van Oers (1998) has argued that it should be regarded as a general theoretical concept, stating that “context is seen here not merely as a synonym for a concrete external situation, but it can assume the character of a mental framework as well” (van Oers, 1998, p. 474). One complicating factor is that the notion of context is sometimes referred to in different ways. In some studies, the contextual setting is discussed in terms of ‘modules’ (e.g. Graeber & Lindner, 2008; Holbrook, Rannikmäe, & Kask, 2008) while others use the notion of ‘themes’ (e.g. Nentwig et al., 2007). It was therefore considered necessary to introduce a more unambiguous definition of context in this thesis.

Whitelegg and Parry (1999) discuss both broader and narrower definitions of ‘context’ and build on the work of Vygotsky by stating that “a learning context requires relating learning to an *application* in the real world” (Whitelegg & Parry, 1999, p. 68). In their narrower definition, contexts are applications of a theory to illuminate and reinforce science. However, they note that merely introducing an application after teaching using conventional methods is unlikely to be very effective. Methods of using context can be analysed through Gilbert’s (2006) four models, which distinguish between context as the application of concepts, contexts as the interplay between concepts and applications, context as a personal mental activity and context as a social circumstance. This work uses the CBL approach proposed by Bennett et al., in which the contexts and applications of chemistry are introduced from the outset of the teaching program and integrated into teaching at every subsequent stage (Bennett, Holman, Lubben, Nicolson, & Otter, 2005; Bennett et al., 2007). Bennett et al. elaborated upon the narrow definition of Whitelegg and Parry (1999) to highlight the close connection between context and scientific literacy. This thesis investigates the interpretation, which calls for regular references to daily life during teaching to illustrate the relevance of the subject matter being taught. Nentwig et al. have proposed a definition that is consistent with those mentioned above and has played a foundational role in this thesis:
It is important in this understanding of chemistry teaching that the context is not a mere motivational trick in the beginning to lure the students into the chemistry. Nor is it an additive in the end to “further illustrate the subject matter” (41). The context is the red thread along which the investigation of the issue in question develops. It begins with the learners’ prior knowledge and experience, it is guided significantly by their questions and interest and it is linked to as many real world experiences as possible. (Nentwig et al., 2007, p. 1441)

This definition strongly emphasises the close relationship between context, prior knowledge, and students’ own questions and real world experiences, and the contributions of all to meaningful learning.

**Context-based chemistry: From past to present**

CBL approaches have been developed in various countries for almost 40 years. The American Chemical Society started designing context-based chemistry curricula and textbooks in the late 1970s as a way to introduce future citizens to chemistry (Ware & Tinnesand, 2005). The curricula comprised different sets of themes that were intended to prepare students to make informed decisions as adults. The early ‘Chemistry in the Community’ curricula lead to the development of several other context-based courses in the US such as the Iowa Project, which was designed with the aim of linking science-technology-society and constructivism to improve people’s beliefs about science education and enhance scientific literacy (Yager & Weld, 1999). Another such program led to the development of the ‘Chemistry in Context’ university curricula (Schwartz, 1999). Studies on these CBL approaches provided important insights into the advantages and disadvantages of CBL relative to more conventional approaches.

In 2006, a special issue of the International Journal of Science Education (Pilot & Bulte, 2006a) introduced and analysed five different context-based chemistry curricula: the ‘Salters’ courses from the UK (Bennett & Lubben, 2006), ‘Chemie im Kontext’ from Germany (Parchmann et al., 2006), ‘Chemistry in Context’ and ‘Chemistry in the Community’ from the US (Schwartz, 2006), an industrial chemistry course from Israel (Hofstein & Kesner, 2006), and a new context-based curriculum from the Netherlands (Bulte et al., 2006). The creators of these curricula issued a message saying that chemistry education has to focus more on what students ‘need to know’ to understand chemistry in everyday life, and must also be aware of students’ difficulties in seeing school chemistry as a cohesive whole. The final outlook paper in this special issue highlighted some aspects relating to the development of context-based curricula that require further investigation.
(Pilot & Bulte, 2006b). Two of these aspects are examined in this thesis. The first relates to items used in assessment and methods for designing good assessment tasks and analysing students’ responses to these items (p. 1107). The second relates to identifying contexts that are appreciated by students and how these contexts can be related to the learning of chemical concepts (p. 1109). According to Pilot and Bulte (2006b), this knowledge is required to enable the development of assessment methods that are compatible with the aim of promoting higher order learning.

In the CBL special issue (Pilot & Bulte, 2006a), Schwartz (2006) compares conventional chemistry courses (which introduce new scientific concepts in a linear fashion) to ladders. Students climb these ladders by grasping each content area (i.e. rung) in succession, a process that some appreciate but presents difficulties to others who find it difficult to see the connections between the rungs. The style and order of presentation of these different content areas in school chemistry courses is often very similar to that in standard chemistry textbooks (e.g. Andersson, Sonesson, Svahn, & Tullberg, 2012; Timberlake, 2009) and chemistry syllabi (Swedish National Agency for Education, 2000). This similarity is so great that in many cases, the titles of textbook chapters are almost identical to those of individual sections of the school courses, e.g. ‘Matter’, ‘The atom’, ‘Chemical bonding’. This conclusion is consistent with previous studies on Swedish textbooks (Bergqvist, Drechsler, de Jong, & Chang Rundgren, 2013). One disadvantage of dividing the material into distinct content areas in this way is that students rarely look back or climb down the ladder, and therefore cannot readily connect their new knowledge to things they learned earlier. However, as discussed previously, prior knowledge is essential for meaningful learning (Ausubel et al., 1968). In contrast to this ladder, Schwartz (2006) likens context-based courses to a spider’s web, with the different content areas and their core concepts being interconnected in a more complex and non-linear way (see Figure 1). This metaphor has a double meaning because the Latin word contextere can also be translated as “to weave together”. A possible advantage of context-based approaches is that students must occasionally move laterally or backwards within the web in order to ultimately move forwards.
Several CBL-like approaches exist, including STS and SSI approaches (Klosterman & Sadler, 2010; Sadler, 2009; Sadler, Barab, & Scott, 2007; Sadler & Zeidler, 2009; Zeidler, Sadler, Applebaum, & Callahan, 2009). Bennett et al. (2007) have found that the term ‘context-based’ is more frequently used in Europe while researchers in North America prefer the term ‘STS’. Scientific content knowledge gains from SSI have been discussed by Klosterman and Sadler (2010), who reviewed research projects using both SSI and CBL approaches and utilise the terms synonymously. Zeidler et al. (2009) differentiate STS from SSI by claiming that the STS movement merely focuses on science in relation to technology and society whereas SSI goes further to involve students in moral problems associated with belief conflicts. This position is consistent with Sadler et al.’s (2006) emphasis on ethical aspects. There are thus multiple definitions and interpretations of SSI. The term ‘context-based’ is used in this thesis because it focuses on everyday life contexts that do not have exclusively social origins or explicitly involve moral dilemmas. However, some STS or CBL approaches do concentrate on these ethical issues – for example, there have been studies on lesson plans relating to potato crisps and musk shower gels (Marks, Bertram,
& Eilks, 2008; Marks & Eilks, 2010). In addition, other studies have treated SSI and contexts as synonyms (Lewis & Leach, 2006), although this complicates the definition of both terms and may confuse readers. Ultimately, the debate about whether to describe a given approach as CBL, STS, SSI or problem-based is not hugely significant; the main objective in all cases is to foster active and independent students via context-led work and to teach students to become engaged learners (Smith, 2011).

**Theoretical background of CBL**

CBL approaches have their origins in the theoretical perspective of situated learning (Greeno, 1998; Lave & Wenger, 1991). Gilbert (2006) and Sadler (2009) have argued about how the ideas of the situated learning perspective can be connected to CBL approaches. Situative teaching emphasises the situation and the context in which learning occurs, focusing on learning transfer (Mandl & Kopp, 2005). The theory of situated learning is rooted in constructivistic approaches, where learning is seen as an active, constructive, emotional, self-directed, social and situative process. Lave and Wenger (1991) discuss situated learning using the concept of legitimate peripheral participation, highlighting the importance of ensuring that students are active participants who feel confident and legitimate. Mandel and Kopp (2005) stress that learning transfer cannot be decontextualised, which is consistent with the findings of HOCS research (Zoller & Levy Nahum, 2012). Context-based chemistry is also linked to activity theory (van Aalsvoort, 2004a), which emphasises the significance to provide settings in the ZPD of students (Gilbert, 2006). Teachers play a key role in this process: they must be attentive, identify each student’s ZPD, and provide each student with the information they require to enhance their conceptual understanding. The processes by which students solve context-based problems must therefore be analysed in relation to the scaffolding provided by the teacher (or the interviewer, in the cases presented herein) in order to see how students actively construct their own higher order thinking.

**Implementation of CBL approaches**

To exemplify how CBL approaches can be implemented in curricula, we consider the reforms that were recently introduced in the Netherlands. In the beginning of the 21st century, the science curricula used in Dutch upper secondary school were revised and new context-based science courses were
introduced (Coenders, Terlouw, Dijkstra, & Pieters, 2010; Driessen & Meinema, 2003; Millar, 2011). Before the implementation, teachers’ conceptions about teaching and learning in relation to CBL approaches were investigated, and van Driel et al. (2005, 2007) highlighted the close connection between teachers’ ideas about what is good knowledge and what they teach. van Driel et al. (2007) identified two distinct teacher groups with different domain-specific beliefs and general beliefs about teaching and learning. The first group emphasised fundamental chemistry in relation to subject-matter oriented teaching and learning, while the second focused on linking chemical knowledge to students’ daily lives in a way that is closely based on learner-centred teaching and learning. These approaches can be likened to Roberts’ (2007) Visions I and II, respectively, and the associated perspectives on scientific literacy.

The Dutch CBL approaches are founded on the ‘need-to-know’-principle, which states that teaching should focus on chemistry concepts that are needed to understand the context (Pilot & Bulte, 2006b). This need-to-know is achieved through the application of contexts, or, according to the terminology of Bulte et al. (2006), through the use of authentic practices. The word ‘practice’ is applied as it relates to actions, not only to a specific situation, and an authentic practice is interpreted as a contextualised problem that is authentic and relevant for the students (Prins, Bulte, & Pilot, 2011; Wickman, 2014). The authentic practice “is not there merely to give students emotional desire to participate but as an ‘advanced organizer’ in terms of Ausubel (1968), which helps the students see what they need to know and do” (Wickman, 2014, p. 152). Through the authentic practice, students are assumed to give meaning to the chemistry they learn. Unfortunately, even though this seems evident, there are several problems with this starting point (Stolk, de Jong, Bulte, & Pilot, 2011).

A more recent Dutch study on students’ perceptions of context-based chemistry teaching after the implementation process indicated that students following the context-based curricula placed less emphasis on fundamental chemistry and teacher-centred methods, but there was no compensatory shift to student-centred approaches and “new” chemistry in the context-based classrooms. In other words, there were no apparent emphasis on the relationship between chemistry and society (Overman, Vermunt, Meijer, Bulte, & Brekelmans, 2014). This suggests that it is essential to consider teachers and their beliefs when trying to implement new approaches (Stolk et al., 2011; van Driel et al., 2007; Vos, Taconis, Jochems, & Pilot, 2011), and to offer teachers opportunities for professional development that will empower them to deliver effective context-based chemistry education (Stolk, Bulte, De Jong, & Pilot, 2009a, 2009b). This is particularly important
because it is hard to implement effective change based on reforms that introduce innovative practices (Davis, 2003). The difficulty of making changes of this sort is demonstrated by the problems Dutch teachers encountered when trying to develop context-based material without assistance or guidance (Overman et al., 2014; Stolk et al., 2011). Stolk et al. (2011) found that the teachers’ strategies for ‘need-to-know’ work were superficial and so they were not empowered by designing their own context-based material. Overall, studies on teachers and CBL approaches indicate that teachers play a central role in the successful implementation of unconventional teaching approaches and while their input is not considered explicitly in this thesis, it must be accounted for when drawing conclusions about the effectiveness of CBL approaches.

Up-to-date implementations of CBL approaches have also been incorporated into the chemistry curricula of Israel and Australia. An Israeli study examined the challenges teachers encountered when implementing a module on food chemistry from a new context-based chemistry curriculum (Avargil et al., 2012). One of the difficulties highlighted by the teachers themselves was that the module forced them to assess both students’ content knowledge and their higher order thinking. In Australia, King and Ritchie (2013) investigated a context-based chemistry programme for upper secondary teaching by analysing students’ learning transactions in a situation where the context (a project examining a local creek) affected teaching practices and classroom interactions. They analysed students’ transfer of knowledge from the real-world creek to the formal chemistry classroom using Vygotsky’s sociocultural perspectives and Bourdieus’s notions of ‘field’, ‘value’ and ‘capital’. Moreover, they highlight characteristics of academically successful students and claim that if teachers are aware of differences in students’ cultural capital, they can create opportunities for all types of students to develop higher order thinking skills (King & Ritchie, 2013). The frequent focus on high-achievers has been challenged by Ellis and Gabriel (2010), whose work examined the impact of CBL on students in general but placed particular emphasis on the achievements of non-traditional students. These authors’ conclusions indicate that for “academically vulnerable students, the results suggest that CBL has the potential to make the transition to university much less difficult” (Ellis & Gabriel, 2010, p. 138), suggesting that CBL has the potential to improve both the recruitment and the retention of chemistry students.
Context-based textbooks

In countries where context-based courses have been incorporated into the curriculum, context-based textbooks have also been developed. In the US, textbooks like the previously mentioned Chemistry in the Community (ACS, 2011) and Chemistry in Context (ACS, 2012) have been introduced; in the UK the ‘Salters Advanced Chemistry’ (Cogill et al., 2009); and in Germany the ‘Chemie im Kontext’ (Demuth, Parchmann, & Ralle, 2006). Since textbooks are perceived as a foundation for teaching (Bergqvist et al., 2013; Kahveci, 2010), research on these textbooks, e.g. from the US (Schwartz, 1999), the Netherlands (Overman, Vermunt, Meijer, Bulte, & Brekelmans, 2013) and Germany (Parchmann et al., 2006) has been influential in clarifying the impact of context-based curricula. In a study on teachers using both context-based textbooks and traditional alternatives, Overman et al. (2013) showed that the mixture of approaches can make it difficult to produce relevant and meaningful tasks. Books of both types contained many similar tasks that focus on the recall of facts, i.e. rote learning. These results indicate a need for better methods of designing and developing context-based tasks that will encourage students to apply higher order thinking, as noted by Pilot and Bulte (2006b). Even in Sweden, where CBL is not formally incorporated into the syllabus, textbooks have been developed by engaged teachers and chemists who translated the Salters’ context-based book from English into Swedish (Engström, Backlund, Berger, & Grennberg, 2001). However, ten years after the version’s publication, it has found limited uptake among Swedish upper secondary schools according to its publishers, and even though Pilling and Wadddington (2005) refer to the Swedish implementation of the context-based book as a success, this does not appear to be reflected in current practices. Nevertheless, parts of CBL approaches could be implemented in countries like Sweden without a formal context-based curriculum, for instance by using thematic chemistry education videos from the Internet (Christensson & Sjöström, 2014) or as in this thesis, which describes the use of context-based chemistry problems to analyse students’ application of chemistry concepts and their problem-solving strategies. The problems presented herein were not introduced solely as examination tasks, but the implications of the problem-solving studies for assessment are addressed at the end of the thesis.

Relevance of chemistry

A focal point within CBL approaches is the importance of relevance (de Jong & Taber, 2014; King & Ritchie, 2012), which is frequently discussed together
with interest and motivation. Students consider chemistry irrelevant since they find it difficult to connect school chemistry to their own lives (Aikenhead, 2006; de Jong, 2006; Sadler, 2009; van Aalsvoort, 2004a, 2004b). Students thus consider the chemistry content offered in school to be of negligible personal relevance, possibly because too little time is spent on establishing relevance in school (van Aalsvoort, 2004b). It is therefore essential to determine what students consider relevant. Gilbert (2006) stresses that teachers have to be observant about what students find relevant; contexts that teachers consider to be relevant may be less so to students. Research projects investigating young people’s interests and opinions about the relevance of science education (e.g. the ROSE study) indicate that areas connected to health and diseases appear to be relevant, especially to girls (Sjøberg & Schreiner, 2010). On the other hand, Sjøberg and Schreiner also point out that topics such as ‘detergents and soap’ are related to everyday life but are not described as relevant by students when asked what they would like to learn about. Conversely, the chemistry interest study conducted by Gräber (2011) indicated that different students responded differently when asked whether the topic of soap was interesting or not. Perhaps both the expression in the question and the example in itself are problematic; there might be other topics connected to everyday life students would prefer to explore (e.g. the chemistry of food or medical drugs). It was therefore decided that this thesis would investigate different topics and contexts to determine how they influence students’ affective and cognitive responses to context-based problems.

**Advantages and disadvantages of CBL**

In general, research indicates that context-based courses are more motivating and interesting than conventional alternatives for both teachers and students, and teachers report that students who complete such courses exhibit levels of chemical content knowledge that are equal to those achieved with conventional courses (Bennett, Gräsel, Parchmann, & Waddington, 2005; Bennett et al., 2007; Sadler, 2009; Schwartz, 2006). However, while several studies have highlighted the advantages of CBL approaches, criticisms have also been raised. In a Turkish quantitative study where the effects of context-based physics instruction were explored by observing both traditional methods and a learning cycle based on a CBL approach, the latter did not lead to any discernible improvement in motivation or induce any clear positive effect on student achievement in physics (Pesman & Özdemir, 2012). Sevian and Talanquer (2014) stress the importance of not neglecting content knowledge or losing sight of the need to convey chemical ideas and
practices when concentrating on the context. The student-centred emphasis commonly applied within CBL approaches might also slow students’ learning progressions by making it difficult to see the chemical concepts in the context (Parchmann et al., 2006; Wickman, 2014).

Furthermore, the contextualisation of tasks might make them more superficial (Marks et al., 2008; Marks & Eilks, 2010), and it has been noted that some previous studies on CBL approaches have methodological issues, requesting a need for better study design (Taasoobshirazi & Carr, 2008). Theoretical and methodological issues in research investigating teaching effectiveness have been raised by Seidel and Shavelson claiming that

> the most striking characteristic of (quasi) experimental research in the past decade might be its heterogeneity in all imaginable facets: The teaching variables studied varied from research to specific training (e.g. metacognitive strategies) to evaluations of broad and intricate interventions (e.g. authentic pedagogy) (Seidel & Shavelson, 2007, p. 464).

These criticisms must be addressed and discussed, acknowledging both more positive findings concerning CBL approaches and contradictory results. As Whitelegg and Parry (1999) stress, the selection of appropriate relevant contexts is vital for CBL approaches to increase students’ motivation. Some of the challenges of this approach are that the new courses might be more demanding for the students, and it can be hard to identify good assessment methods (Bennett, Gräsel, et al., 2005; Bennett et al., 2007; de Jong, 2008; Gilbert, 2006). A key goal of this thesis was therefore to identify appropriate topics and contexts for CBL, and to develop analytical frameworks for designing new context-based tasks and exploring students’ responses to these tasks. Content concerns have also been addressed by maintaining a clear focus on chemistry within the context-based tasks students were asked to complete. To address certain methodological issues, the final empirical study of the thesis (see paper 5) adopted a more rigorous design that was informed by the results and experiences gathered while conducting its predecessors.
Methodology

A mixed methods approach was used to explore students’ affective and cognitive responses to their upper secondary chemistry studies. Mixed methods techniques involve the mixing and comparison of different data sets, which are then analysed as a whole (Cohen, Manion, & Morrison, 2011; Creswell, 2011; Denscombe, 2010a). A wide range of empirical data was collected during this thesis work, and to get a comprehensive overview of the results obtained, it is important to examine it at different scales, moving from detailed analyses of small pieces to more general and broader conclusions (Cohen et al., 2011). According to Denscombe (2010a) mixed methods are useful for improving accuracy, obtaining a more complete picture of the phenomena and processes of interest, compensating for strengths and weaknesses, developing analyses, and as an aid to choosing samples for follow-up studies. These features were exploited in this work when using the results of exploratory and pre-studies to inform the design of the main study.

Mixed methods research

A great variety of methods can be used to investigate the complex processes of teaching and learning. There have, for many years, been extensive debates among social scientists about the relationships between quantitative and qualitative research. Qualitative research is considered interpretative and exploratory, emphasising words rather than quantification in gathering and analysing the data. Quantitative research, on the other hand, is often conceived as normative and empirical. Discussions have been undertaken to define whether the two approaches should be regarded as different paradigms or as different methodological aspects within the same paradigm. Hanson (2008) argues that the division of the two is mainly a political rather than an intellectual issue. Åsberg (2001) similarly states that this binary division of approaches is overly simplistic, and it is not the case that quantitative research is objective, systematic and generalisable whereas qualitative research is subjective and impossible to generalise. Both approaches have advantages and disadvantages, so it is beneficial to combine them. Cohen, Manion and Morrison (2011) argue that mixed methods research is the new research paradigm of educational sciences, combining quantitative and qualitative data to get a broader picture of the researched object in a way that exploits the complementary qualities of the two research styles (Chatterji, 2004; Markic & Eilks, 2012).
When discussing paradigms within educational research from a broader perspective that extends beyond methods, mixed methods research is characterised as moderating the initial antagonism between different research paradigms, such as post-positivist, interpretivist and critical theory research (Treagust, Won, & Duit, 2014). It can therefore be seen as a compromise that accommodates; “qualitative researchers’ practical attempts to establish themselves in a post-positivist-dominated academic world without committing themselves too much to the interpretivists’ research paradigm” (Treagust et al., 2014, p. 13). To define Treagust et al.’s interpretation of the post-positivist research paradigm, some central statements have to be considered. First of all, post-positivists rely on logical reasoning and empirical data; however as opposed to positivists they argue that our surroundings influence our perceptions of the world. Secondly, given the aim of being as objective as possible, the research must be underpinned by systematic approaches and comprehensive empirical data. Finally, the aim of this kind of research is to explain educational phenomena in a rational way, and hopefully to understand what works in educational practice and why (Treagust et al., 2014).

Because this thesis presents the results of postgraduate studies, one objective of the research presented herein was to gather data using different methods and analytical procedures. Consequently, both quantitative and qualitative research was performed. Quantitative data were collected initially, after which qualitative data were gathered to explain and elaborate upon the initial results, i.e. an explanatory design was used (Creswell, 2011). For information on the different studies and their relationship to the papers included in this thesis, see Table 2.
**Table 2. Empirical data collected for this thesis**

<table>
<thead>
<tr>
<th>Study</th>
<th>Empirical data</th>
<th>n</th>
<th>Focus</th>
<th>Analysis</th>
<th>Paper</th>
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<tbody>
<tr>
<td>Exploratory study 1</td>
<td>Questionnaire 1</td>
<td>372 students, 18 teachers</td>
<td>Students’ opinions on their school chemistry</td>
<td>Quantitative</td>
<td>1</td>
</tr>
<tr>
<td>Exploratory study 2</td>
<td>Questionnaire 2</td>
<td>495 students</td>
<td>Students’ interest in and choice of chemistry</td>
<td>Quantitative</td>
<td>2</td>
</tr>
<tr>
<td>Pre-study</td>
<td>Classroom observations</td>
<td>44 hours</td>
<td>Background information</td>
<td>Qualitative</td>
<td>(3)</td>
</tr>
<tr>
<td></td>
<td>Chemistry test items</td>
<td>38 items</td>
<td>Types of examination tasks</td>
<td>Qualitative &amp; quantitative</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Written responses to one context-based task (Tamiflu)</td>
<td>236 students</td>
<td>Problem solving of context-based tasks</td>
<td>Qualitative &amp; quantitative</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Think-aloud interviews on the Tamiflu task</td>
<td>9 students, 5 chemistry professors</td>
<td>Problem solving of context-based tasks</td>
<td>Qualitative</td>
<td>4</td>
</tr>
<tr>
<td>Main study</td>
<td>Student think-aloud interviews on 15 context-based tasks</td>
<td>20 students 2 tasks each</td>
<td>Problem solving of context-based tasks</td>
<td>Qualitative &amp; quantitative</td>
<td>5</td>
</tr>
</tbody>
</table>

**Methods and analysis**

The quantitative data analysed in paper 1 (Broman, Ekborg, & Johnels, 2011) and paper 2 (Broman & Simon, 2014) were gathered via questionnaire surveys. The empirical data from these two exploratory questionnaires were mainly analysed using descriptive statistical methods, but some inferential analyses were also performed, mainly simple non-parametric tests (Agresti & Finlay, 2009; Cohen et al., 2011; Pallant, 2010). The decision to primarily rely on descriptive statistics was made because Reid (2011) emphasises the hazards of drawing conclusions from ordinal survey data, which are ‘soft’ because humans interpret the response options differently. Furthermore, Bennett et al. (2001) have identified potential methodological issues with surveys of this type; measurements of affective constructs have been associated with several problems including ill-defined key terms, poorly
designed instruments, limited validity and reliability, a lack of connection between theoretical frameworks and analysis, and unclear interpretations of data. The questionnaires therefore included only a few questions with a limited number of possible responses in order to avoid unduly complicating their completion by the students and to permit the use of simple descriptive statistics. However, while both questionnaires have several closed questions with limited numbers of response options, they also include open questions. The responses to these open questions were coded and so limited qualitative analyses of the data were undertaken. Denscombe (2010a) emphasises that open and closed questions both have different advantages and disadvantages. The main advantage of open questions is the possibility for the respondents to show complexity and express their own ideas, and the advantage of closed questions is the possibility to obtain structured quantifiable data. The response rate on each question in a questionnaire is vital; even though many students might participate in the questionnaire as a whole, different questions might vary in response rate. This may favour either open or closed questions - some respondents prefer to answer with their own words while others prefer ticking boxes. By combining both open and closed questions, a more comprehensive picture can hopefully be obtained.

For paper 3 (Broman, Bernholt, & Parchmann, 2015), both quantitative and qualitative data were analysed to assess chemistry examination tasks and students’ written answers to one representative context-based task. Thirty-eight items from a chemistry examination were qualitatively analysed according to the HOCS/LOCS-framework (Zoller & Dori, 2002) and the chemistry syllabus (Swedish National Agency for Education, 2000). Classroom observations were performed to obtain background information on chemistry education from the classroom from where the chemistry examination had been conducted and to be able to relate the students’ stories about their chemistry lessons to my own observations. As discussed by Denscombe (2010a), it was also important to observe other teachers’ chemistry lessons rather than just considering my own, because past experiences influence our interpretation and “we tend to see what we are used to seeing” (Denscombe, 2010a, p. 198). These observational data were not analysed in-depth but was used in the analysis of the test items - to determine whether a given item merely required factual recall, it is necessary to consider students’ experiences from the chemistry classroom and textbooks. The observational data were also useful when validating students’ interview responses concerning their teaching in the chemistry classroom.

One context-based task from the chemistry test items that required students to apply higher order cognitive skills was examined in more detail by
investigating 236 students’ written responses. The item in question related to the medical drug Tamiflu. The students’ responses were analysed, primarily in a qualitative way using both the frameworks applied when evaluating the chemistry examination, i.e. HOCS/LOCS and the syllabus, in combination with the more focused MHC-C (see Table 1; Bernholt & Parchmann, 2011). Furthermore, some descriptive quantitative analysis was also done to summarise and get an overview of the students’ responses.

Finally, the two last papers (Broman & Parchmann, 2014; Parchmann, Broman, Busker, & Rudnik, 2015) mainly relied on qualitative analyses of empirical data from think-aloud interviews with students and experts (chemistry professors) as they solved context-based chemistry problems (Bogdan & Knopp Biklen, 2007; Cohen et al., 2011; Creswell, 2011). The interviews were semi-structured (Denscombe, 2010a; Kvale & Brinkmann, 2011) and followed a previously planned interview protocol that was intended to scaffold the students’ problem-solving process by prompting in keeping with the supporting tools identified by Fach et al. (2007) and the MHC-C-operators of ‘name, describe, and explain’ (Bernholt & Parchmann, 2011). In the main study, during which the empirical data for paper 5 were collected, 15 new context-based problems were designed and developed according to structured and planned design principles. The contextualised origin of the problems was selected in accordance with the first three contexts proposed by de Jong (2008); his forth origin of context (i.e. the scientific/technological context) was excluded because it did not fit into the format of the problems. The topics were then characterised using de Jong’s criteria for selecting adequate topics, which state that topics should be well-known and relevant, should not distract students’ attention from related concepts, should not be too complicated, and should not be confusing. For more detailed information about the study’s design principles, see paper 5.

The Swedish school system

Compulsory education in Sweden lasts for nine years, but most (98.5% according to statistics from The National Agency for Education, 2013) students apply to an upper secondary programme after completing their compulsory studies. Today, upper secondary school comprises 18 three-year long national programmes, although only 17 were in operation when the studies presented herein were conducted (for more information on the Swedish school system at the time of the data collection, see Lundahl, 2011; Risch, 2010). During compulsory schooling, science in the form of chemistry, biology and physics, is studied by all students in all grades. However, at the
post-compulsory upper secondary level, these three subjects are only studied separately by the students choosing the Natural Science Programme (NSP) or the Technology Programme. In the NSP, chemistry is studied at the highest level possible prior to university; this program is selected by 12-14% of each year’s compulsory school graduates (Swedish National Agency for Education, 2014). The NSP prepares students for university studies in all subjects but since its participants are able to take the most advanced courses in science and mathematics available at the upper secondary level, this programme is regarded as the programme for ‘future scientists’ (Anderhag et al., 2013). In a project on chemistry education in different educational systems, Risch (2010) compared 25 countries’ chemistry education programmes to identify “best-practice-models” and he identified two core themes; the countries with most successful educational systems focus on competent teachers and have a high-status teacher education, and an important difference between countries is that some curricula teach science as a single general subject, whereas others teach chemistry, biology and physics respectively. Without recommending science as a general subject or dividing it into single ones, Risch emphasises that educational-political discussions are complex and states that it is naive to assume “that a successful educational model can simply be taken over by other countries” (Risch, 2010, p. 9). In Sweden, teacher education has low status and few students apply for teacher education within natural science.

Sample

The students participating in this thesis were purposefully sampled by applying Denscombe’s sampling techniques (Denscombe, 2010a). In the exploratory survey studies (papers 1-2), contacts were made with teachers through The Swedish Chemical Society and The National Resource Centre for Chemistry teachers (KRC), via which teachers were invited to participate with their chemistry classes. However, there was an intentional choice to investigate students from different parts of Sweden, from smaller and larger cities, and from more or less popular schools to get a more comprehensive picture, so a stratified or quota sample was obtained (Cohen et al., 2011; Denscombe, 2010a). The choice to avoid random sampling was mainly made to achieve a high response rate; using willing teachers was expected to yield a greater response rate. However, it should be noted that this may have affected the results obtained, which must be borne in mind when discussing their generalizability. A very similar sampling protocol was used when selecting students’ written responses to the representative context-based task in paper 3, during which their teachers were contacted and asked to
participate. Moreover, in the qualitative studies (i.e. papers 4-5), the interviewed students and chemistry professors were chosen deliberately to get as detailed results as possible, i.e. purposive sampling was performed (Bogdan & Knopp Biklen, 2007; Cohen et al., 2011; Denscombe, 2010a).

Students’ affective domain: Two exploratory studies

To get an overview of students’ opinions of their school chemistry and their reasons for studying chemistry at upper secondary school, two survey studies were conducted; these are presented in papers 1 and 2. The first exploratory study was conducted in 2007 to gather background material for the research project. A questionnaire was submitted to 372 students and their 18 teachers to investigate the students’ opinions of their chemistry education. The results of this exploratory study paved the way for the later work presented herein. The first exploratory study is described in detail in paper 1 (Broman et al., 2011). The second exploratory study (Broman & Simon, 2014) was carried out within the context of a statistics course for PhD students in the autumn of 2010, where 495 upper secondary chemistry students completed a short questionnaire building on results from the first exploratory study. One purpose was to examine differences in question posing, which was done by asking the same question in an open way during the first study and as a closed question in the second. The idea was to use the responses from the open question to generate response options for the students to rank and to thereby investigate the same issue from two perspectives. In this second questionnaire, questions on student choice and student interest were also posed to get more background information on students’ views about their school chemistry courses.

Students’ cognitive domain: Pre- and main study

The main conclusion from the first two studies was that students strongly desired to connect their chemistry education to their daily lives. This prompted an investigation into context-based learning (CBL) approaches. The work of Pilot and Bulte’s (2006b) stresses the need to investigate appreciated contexts in detail, to design and develop context-based tasks, and to analyse students’ responses to these tasks. As a consequence, both a pre- and a main study were conducted to examine students as they attempted to solve context-based problems. The pre-study, which was conducted in 2011, focused on chemistry test items and students’ responses to one specific task. To analyse students’ problem-solving processes in detail, a representative context-based problem was scrutinised by analysing 236
students’ written responses to this task and by using semi-structured think-aloud interviews to characterise nine students’ and five experts’ problem-solving strategies as they worked on the problem in question. For detailed information on the methods used, see papers 3 (Broman et al., 2015) and 4 (Parchmann et al., 2015).

The pre-study investigated only one context-based task. To obtain a more wide-ranging analysis of CBL in chemistry, the main study (paper 5) was based on 15 new context-based problems that were designed and developed using a clear set of design principles. The design process, which began in 2013, had three explicit and pre-planned steps; (1) to focus on limited content areas using concepts found in the syllabus (Swedish National Agency for Education, 2000), (2) to develop tasks relating to five different topics (i.e. medical drugs, energy drinks, fats, fuels, and soaps and detergents) based on results from the ROSE study (Sjøberg & Schreiner, 2010) and Gräber’s (2011) chemistry study, (3) to contextualise the tasks into three different settings, i.e. personal, societal and professional contexts (de Jong, 2006, 2008). Students (n=20) were requested to solve two problems each using think-aloud techniques in semi-structured interviews (Denscombe, 2010a; Kvale & Brinkmann, 2011). The students initially worked on the problems without assistance but were provided with scaffolding by the interviewer if required. The scaffolding process was designed with reference to the stepped supporting tools discussed by Fach et al. (2007) and the MHC-C operators of name, describe, and explain (Bernholt & Parchmann, 2011). To analyse the qualitative empirical data, content analysis was conducted using the steps outlined by Denscombe (2010a). For detailed information about the methods used, see paper 5 (Broman & Parchmann, 2014).

In combination with the students’ problem-solving strategies, their affective responses to the context-based tasks were also monitored. Before solving the two problems as mentioned above, they were assigned six of the 15 tasks, i.e. two topics from three contextualisations each. After reading the task through, they commented on how interesting, relevant and difficult they perceived each one to be, and selected which of the three contextualisations they would prefer to work on. The findings concerning students’ affective responses to the tasks are only discussed briefly in paper 5 and therefore some additional results will be presented in the results section of the thesis. They will also be analysed at greater length in forthcoming non-thesis publications.
Good practice in the research process

Several ground rules were established to ensure good practices in the research process (Bogdan & Knopp Biklen, 2007). Educational research involves humans, and ethical concerns have to be reflected thoroughly in the process. Various ethical checklists are found in research methodology literature; this work was guided by the ground rules for social research presented by Denscombe (2010b). These rules state that to produce good research, the research topic must have a purpose while also being relevant and feasible to assess. In this thesis, the purpose was to explore upper secondary chemistry, which is very relevant to both chemistry education research and modern society. It was essential to ensure that the research approach was objective and ethical, the study design was coherent, and the underlying assumptions were identified and known. In Sweden, the Research Council has ethical rules and guidelines for educational research (Swedish Research Council, 2002, 2011), which were followed throughout the entire research process. Since individual students’ responses would be very difficult to discern in the broad empirical data, there were no concerns about any risk of violating students’ anonymity. Moreover, the participating students were at the end of their upper secondary education and 18-19 years old. As such they were treated as adults, so their parents’ written consent was not required.

It was also essential to ensure that the methods used were accurate, with high validity and reliability, and that the data were collected and used in a justifiable way. Validity and reliability are fundamental methodological terms but they are not always applied in an explicit way, perhaps mainly because there are many different types of validity and reliability (Cohen et al., 2011). According to Denscombe (2010b), the key point is to determine whether the research is based on valid data and reliable methods. For example, in a comprehensive review of science attitude instruments used between 1935 and 2005, Blalock et al. (2008) discuss validity and claim that one problem with much attitude research is that many researchers want to develop their own research instruments rather than taking advantage of existing experiences. Fortus (2014) agrees with this point about the difficulty of designing valid instruments, stating that it is time-consuming to develop high-quality tasks, and suggesting that there should be a “compendium of accepted instruments to which one goes when wanting to measure an attitudinal aspect” (Fortus, 2014, p. 825). Unlike the situation for subjects such as chemistry, it is not generally feasible to repeat educational research studies on students in the same way you could when dealing with substances in a test tube. Social settings are not replicable and the educational researcher is more personally involved in both the data collection and the
analysis, making it challenging to achieve objectivity (Denscombe, 2010a). The complexity of assessing the reliability and validity of the studies in this thesis is discussed in the concluding section.

Finally, the findings should be at least somewhat generalizable and contribute new knowledge. According to Bogdan and Knopp Biklen (2007), generalizability refers to whether the findings of a study hold up beyond the studied setting and research subject. Since the samples examined in this thesis were not random, it is not statistically correct to claim generalizability. However, since several choices throughout the research process have been well-reasoned and both the student and task samples were selected to be representative or facilitate the investigation of particular characteristics, Denscombe’s (2010b) ideas on generalizability and transferability have been adopted. These general ideas on improving the research process became increasingly central over the course of this work, and there is a clear progression with respect to these considerations from the first study to the last, especially in terms of explicitly stating assumptions that are made. A key point that helps to ensure a high quality research process is to reflect on the study’s design before collecting empirical data, as was done in the main study. This growing awareness of the importance of the research process is discussed at greater length in a reflexive book chapter on making the transition from practitioner to researcher (Broman, submitted). Moreover, Denscombe’s (2010b) ground rules are discussed critically in relation to the results obtained in the conclusion of this thesis.

Unquestionably, this work has both strengths and limitations. Apparent strengths are the practitioner’s experience, the familiarity with the setting, and the use of a mixed methods approach that enables triangulation of the obtained results. All research designs have limitations; methodological issues have been highlighted above and will be discussed further after presenting the results. To draw conclusions from a research project like this, it is essential to be aware of potential methodological weaknesses. The studies’ aims and research questions were used to define boundaries to include some parts and exclude others in this project. Limitations and other methodological issues (i.e. validity, reliability, generalizability) are discussed further at the end of the thesis.
Summary of the papers

This section outlines the five papers included in the thesis. Additional results and the research process that yielded the results presented in the papers are discussed in the following chapter.

Paper 1: Students’ and teachers’ opinions on school chemistry

The first paper in the thesis describes an exploratory quantitative study investigating students’ and teachers’ opinions of their school chemistry (Broman et al., 2011). A questionnaire for students (n=372) and their teachers (n=18) was used to gather data on students’ views of different content areas, if the areas were more or less interesting and more or less difficult; students’ ideas on working methods; and students’ ideas on how to improve school chemistry to make the subject more meaningful and interesting. These results were compared to the teachers’ responses and ideas. The most important affective construct used in this paper was interest because it played a central role in two of the study’s four objectives (determining which content areas were considered more or less interesting, and asking students and teachers how to make school chemistry more interesting).

The results show that students consider some content areas such as atomic structure to be easy while others are more difficult, e.g. chemical analysis. The opinion that atomic structure is an easy area was discussed in relation to other research identifying this area as a difficult threshold concept (Park & Light, 2009). In Swedish textbooks, this topic is presented in a simplistic and descriptive way (i.e. the shell model instead of the orbital theory), which may make it subject to rote learning and perceived irrelevance. However, in addition to being easy, students also state that atomic structure is interesting. This contradicts previous findings from the Swedish ROSE study (Jidesjö et al., 2009; Oskarsson, Jidesjö, Karlsson, & Strömdahl, 2009), in which students stated that ‘atoms and molecules’ was one of the least interesting scientific topics. This result implies that the results of the ROSE study, which examined 15-year olds, are not directly transferable to older upper secondary students. The teachers agreed with their students on most content areas but there was one about which students and teachers clearly disagreed; students claimed that chemical bonding is an easy area whereas their teachers claimed the area to be difficult for their students. When
investigating which areas students considered more or less interesting, organic chemistry and biochemistry were highlighted as most interesting whereas energy and enthalpy were identified as being least interesting. Besides being interesting, biochemistry was also considered difficult.

Regarding working methods, students emphasise teacher-centred chemistry lessons as something they appreciate, and they claim they learned chemistry effectively from listening to the teacher. The working method the students liked the least was working on their own but even then 2/3 of the students claimed to learn chemistry effectively via student-centred methods.

At the end of the questionnaire, students were asked to suggest ways of improving their school chemistry to make it more meaningful and interesting. The question was open, allowing students to express their ideas without interference from the questionnaire. The most common response was to increase the amount of laboratory experiments and establish more connections to everyday life. Nevertheless, several students claimed that they were satisfied with their chemistry education. This open response, in which several students explicitly reported satisfaction and positive opinions about the different working methods, supports one of the starting point of this work, i.e. that Swedish upper secondary students in the Natural Science Programme are pleased with their school chemistry. A final conclusion from the first paper is that school chemistry has to be treated as a subject that involves more than mere recall of factual knowledge to make it interesting and meaningful to students, that role models are central for students, and that competent teachers are essential for improving chemistry education.

**Paper 2: Students’ choice of post-compulsory chemistry**

The second exploratory study (Broman & Simon, 2014) was a follow-up study exploring students’ opinions about their chemistry education and their suggestions on how to improve school chemistry, but also aiming to more explicitly investigate students’ decisions to study post-compulsory chemistry. Since Swedish students specialise when entering upper secondary education, their reasons for choosing a programme with a science specialisation were investigated. Theoretically, students’ choices were elaborated in relation to their reported interests and perceptions of the relevance of chemistry using the frameworks of Bennett et al. (2013) to describe categories of choice strategies, and interest research from Bøe et al. (2011) and Holmegaard et al. (2014a). In paper 2, students at the end of an upper secondary chemistry
programme were asked why they chose a course of study (i.e. NSP) with the
greatest possible chemistry content, and to give their opinions on chemistry.

The students (n=495), from different schools and different parts of Sweden,
claimed that their main reasons for choosing post-compulsory science is
because of the opportunity to enter higher education (84%), and because
they enjoy science (54%). Positive opinions regarding school chemistry were
also given when the students were asked to grade their chemistry education;
73% found it good or very good. In other words, students’ general interest-
enjoyment value is high. When the students had the opportunity to justify
their opinions in an open question, the most common response was that
chemistry is fun and interesting. Moreover, students emphasise the
significance of the teacher and notably the teachers’ instructional pedagogy
by highlighting the structure of chemistry lessons. The third most important
reason for choosing the NSP was a deliberate desire to attend a specific
school. In Sweden, at least in bigger cities, NSP can be studied at different
schools, therefore students both have to choose a programme as well as a
particular school. Almost half of the students claim that this informed their
choice – they wanted to go to a specific school. Schools can be specific in
different ways; some upper secondary schools have orientations towards
specific topics, such as aesthetics or sustainable development. Some are also
independent schools not governed by the municipality (which is the case for
most schools); others differ in terms of the programmes they offer. In
accordance with the framework of Bennett et al. (2013), this is defined as
‘school ethos’. A choice of a given school ethos is understood as an identity
choice that depends on the individual’s identity; students choose post-
compulsory chemistry in relation to a school where they feel “at home”. Since
gender is often mentioned as a central variable within science education,
gender differences were also explored. Within science education it is
common to use the term ‘gender’ even though it would be more correct to
use the term ‘sex’ since most studies compare boys and girls, i.e. biological
sex. Nevertheless, in this study no significant gender (i.e. sex) differences
were identified.

The participating students were also asked to answer a question from the
first questionnaire (cf. paper 1) on how to improve their chemistry education
and make it more interesting and meaningful. However, whereas this
question was open in the first study, it was closed in the second; students
were asked to rank three response options out of 17. The most common
suggestion was to make more connections to everyday life (58% of the
students marked this response option as important by giving it a rank of 1-3).
Other central improvements are more laboratory work (48% of the students
ranked this as 1-3), more student-centred working methods (28%), better
teachers (27%), more educational visits (25%), and better chemistry textbooks (24%). The least selected response option was to reduce the time spent in chemistry lessons, suggesting that students have no desire to avoid chemistry lessons. The main conclusion from the second paper is that students who have chosen to study post-compulsory chemistry, in other words possible future scientists, have overall positive opinions and value their chemistry education. This positive cohort of students highlight the importance of the teacher, that students’ identity construction has to be considered when investigating their educational choices, and that the link between everyday life and school chemistry is important and should be developed and emphasised within chemistry education, for example through CBL.

**Paper 3: Students’ written responses to an exemplary context-based task**

In paper 3 (Broman et al., 2015), the aim was to elaborate an analytical framework that can be used when designing and developing context-based tasks, and when analysing responses to such tasks. Emanating from Bloom’s taxonomy (Anderson & Krathwohl, 2001; Bloom, 1956), which has foregrounded the Swedish curricula for several decades, and since previous research on Swedish upper secondary school chemistry emphasised advantages with applying Bloom’s taxonomy when analysing alignment between assessment and standards (Näsström & Henriksson, 2008), more specified frameworks have been applied. To analyse students’ skills when solving problems and to define tasks, the HOCS/LOCS-framework (Zoller & Dori, 2002) was used. From this framework it was first of all possible to define the tasks in themselves as LOCS or HOCS exam questions. Moreover, when analysing both the tasks and students’ responses it was necessary to analyse the demanded content knowledge, therefore the syllabus (Swedish National Agency for Education, 2000) for the chemistry course had to be added to the analytical framework. Finally, to explicitly explore the complexity of students’ chemistry knowledge, the more specified MHC-C-framework (Bernholt & Parchmann, 2011) was supplemented to the two already described.

At first, an exemplary chemistry test with n=38 test items, both conventional and context-based tasks were analysed applying the HOCS/LOCS-framework. The tasks were, using Zoller and Dori’s (2002) framework, defined as LOCS or HOCS exam questions and the results highlight chemistry test items that almost exclusively require lower order cognitive
skills (i.e. factual recall). Thereafter, students’ (n=236) written responses to one representative HOCS context-based task were analysed in-depth through content analysis and by applying all three frameworks, i.e. HOCS/LOCS, MHC-C and the syllabus. The results highlight an evident emphasis on LOCS exam questions and on recall of factual knowledge in the students’ responses even though the task requests students to apply higher order cognitive skills such as transfer of content knowledge from different content areas. When students tried to solve the context-based task, they mainly recalled facts the teacher had mentioned in the chemistry lessons or facts they had read in their chemistry textbook. It was also apparent that students tried to solve the problem by using content knowledge from the content area they had studied most recently: students who solved the task after reading biochemistry often gave different responses to students taking an organic chemistry exam.

When evaluating the three different frameworks applied in the analysis, the combination of them proved suitable for the sophisticated analyses of both different types of tasks as well as students’ responses to one exemplary context-based problem. The MHC-C was found to be particularly useful and robust, making it interesting and worthwhile to apply this framework to a bigger student cohort and with more tasks. Even though the pre-study has an apparent limitation of only analysing one context-based task in-depth, an important conclusion is drawn in paper 3: even when dealing with tasks that permit the use of higher order cognitive skills, students still mainly apply LOCS. It is thus essential to emphasise the importance of moving beyond recall of factual knowledge by giving the students more opportunities to practice solving more open tasks where higher order thinking is required. One important implication of the paper is that it is important to make students aware of their problem-solving strategies by presenting problem-solving steps and analytical frameworks to them in order to guide their problem-solving attempts.

**Paper 4: Students’ and experts’ problem-solving strategies**

In a book chapter on context-based chemistry on school and university level (Parchmann et al., 2015), a more in-depth analysis of the problem-solving process when upper secondary students (n=9) and chemistry professors (n=5) orally solved the same context-based task as in paper 3 is presented together with German research on CBL at the university level. The reason to compare students’ responses to experts’ was to see how novices and more experienced chemistry professors (who have enough factual knowledge to solve the problem in a more complex way) differ in their approaches.
In the semi-structured think-aloud interviews, nine students were selected from the group who had solved the context-based task in a pen-and-paper test three weeks earlier, cf. paper 3. They were given a blank task without being able to see their earlier written responses, even though the interviewer (i.e. me) had studied their responses in advance. Nevertheless, all students began by carefully reading the newspaper article supplied as part of the exercise to look for useful information. After realising that the article was not helpful, their only expressed strategy was to try to remember what the teacher had said or what the student had read in the textbook. The results from the interviews emphasised the results from paper 3, with the students’ focusing on recall of factual knowledge. After encouragement from the interviewer to attempt a solution anyway, and since the task material included the structural formula of the Tamiflu molecule, students tried to describe the molecule’s chemical structure since “a structural formula means chemistry”. However, the students only concentrated on small parts of the formula and as the functional groups were different to those students had seen previously (i.e. the molecule is water soluble and capable of hydrogen bonding due to amino groups rather than hydroxyl groups), their descriptions and reasoning were often incorrect. The students’ misconceptions about chemical bonding, especially regarding hydroxyl groups and water solubility, were consistent with previous research in this area (Levy Nahum, Mamlok-Naaman, Hofstein, & Taber, 2010). Through follow-up questions, more information was extracted from the students both about their content knowledge and their own ideas about their problem-solving strategies.

The experts, as expected due to their greater content knowledge, solved the problem on a higher complexity level and discussed the molecule as an entity rather than a disparate set of functional groups. The experts were obviously also more precise in their use of chemistry concepts, for example polarity, electronegativity and solubility. When asked about their ideas about students’ difficulties when solving a task like this, the experts were aware of most of the difficulties even though the misconception about hydroxyl groups as the functional group that makes a molecule water-soluble was surprising. One major conclusion from the interviews was that it is important to very carefully consider the design of the tasks. To more explicitly understand the process of problem solving, the tasks have to be more carefully elaborated and only thereafter the scaffolding through hints or prompts can be monitored through the application of analytical frameworks, e.g. MHC-C.
**Paper 5: Students’ use of chemical concepts in context-based tasks**

In the fifth paper (Broman & Parchmann, 2014), there was an evident content emphasis; students’ applied chemistry knowledge was analysed according to both the content areas and the concepts used. At first, 15 new context-based problems were developed using clear and structured design principles. The content areas with their concepts, the topics and the contexts were chosen and applied in a beforehand planned way to make the tasks as well-reasoned as possible. After designing the 15 context-based problems, semi-structured think-aloud interviews were made with 20 students at three different schools. Each student met six tasks; two beforehand chosen topics in three different contexts (personal, societal and professional) and then the students had to decide which contextualisation they wanted to solve. To investigate students’ affective responses, the students responded to a short survey about how interesting, relevant and difficult they perceived the different tasks and how the tasks resembled tasks they met in chemistry class, both regarding topic and context. Thereafter the students started to solve the tasks on their own and depending on how they proceeded, the interviewer only came up with clarifying questions or by scaffolding with more concrete hints. The hints were given according to Fach et al.’s (2007) stepped supporting tools and by applying the MHC-C-operators; name, describe and explain (Bernholt & Parchmann, 2011). Through this, both affective responses as well as cognitive learning outcomes through applied content knowledge and the problem-solving process could be monitored.

When analysing the responses, it was obvious that students focused on recall of memorised facts; lower order thinking was evident, for example by concentrating on finding functional groups in the organic molecules given in the tasks. Students were trying to give “the correct answer”, and claimed that reasoning in a more open and broad way and higher order thinking was uncommon in chemistry. When studying common misconceptions, several previously found misconceptions were also found in these students’ responses, e.g. difficulties with intra- and intermolecular bonding (Levy Nahum, Mamlok-Naaman, et al., 2010) and anthropomorphic explanations (Adbo & Taber, 2013). Finally, when exploring how students make use of the contextualisation of the tasks, it was apparent that students actually used the context in their responses; the connection to everyday life was not a distracting element in the task. One conclusion from the interviews was the unfamiliarity with higher order thinking; hence the use of context-based chemistry problems related to everyday life is a possible solution to improve students’ problem-solving competencies.
Results and Discussion

The analyses presented in this section build on the findings from all five publications as a whole, together with some additional unpublished data.

Affective variables

This thesis investigates Swedish upper secondary students at the end of their non-compulsory studies in the Natural Science Programme. Two exploratory survey studies were conducted to clarify the students’ perceptions of their school chemistry education and identify interesting issues meriting further investigation. Overall, these investigations showed that the participating upper secondary chemistry students felt positive about their school chemistry courses and found the subject interesting. When explaining why they chose to study post-compulsory chemistry, many of the students said it was a prerequisite for their planned future studies but around half also said that they chose a science programme because they enjoyed science. Needless to say, it is not sufficient for only half of all chemistry students to enjoy their studies, and there is clearly scope for further improvements in chemistry education. When asked to suggest ways of improving the chemistry course, the students recommended making more connections to everyday life, increasing the amount of laboratory work, and adopting student-centred working methods. These findings are clearly consistent with those of previous investigations into interest in chemistry (Gräber, 2011). Moreover, the students also stressed the importance of good teachers, especially teachers who provide structured instruction and clearly communicate their intentions. The introduction of this thesis discussed a report on science education in Europe that similarly emphasised the importance of teachers. “Good science teachers are knowledgeable about science and its nature; have some understanding of basic educational ideas; use a range of teaching strategies; have excellent communication skills; and last, but not least, hold a passion for science” (Osborne & Dillon, 2008, p. 25). This quotation highlights the challenge of being a good chemistry teacher; hopefully some of the results presented herein may give interested teachers at least a few new ideas about how to develop their teaching skills and thereby improve upper secondary school chemistry education.

The aim of the exploratory studies was to obtain an overview of upper secondary students’ ideas about their school chemistry. My previous experiences as a practitioner had led me to believe that significant numbers
of students feel positively about chemistry; an additional aim of these initial investigations was to determine whether this was merely due to personal bias or reflective of a general trend. Unfortunately, because the first study was conducted during the early stages of my doctoral work, its theoretical foundations were not as clearly defined and articulated as would have been ideal. To rectify this, some more concrete interest frameworks are outlined in the background section of this thesis and in paper 2. Subsequent reanalysis of the study’s findings from a broader perspective suggested that the students’ opinions of different content areas and their perception of these areas as being easy or difficult may have been influenced by the order in which they were taught during the chemistry courses: atomic structure is the first content area to be covered while biochemistry is the last. Because the students and teachers had different opinions about the difficulty of understanding chemical bonding, this topic was selected for further investigation. The key finding from paper 1 was that students generally held positive opinions about their upper secondary chemistry studies. This result was explored further in paper 2 to determine why students choose to pursue post-compulsory science education. The results presented in paper 2 are consistent with and complement the findings concerning the students’ positive opinions about teacher-centred working methods as reported in paper 1. Overall, the two exploratory studies indicated that students would like the chemistry courses to be more strongly linked to everyday life, which is a core principle of CBL approaches. The later studies built on this point and the students’ ideas for improving school chemistry education.

An additional goal of the first two studies was to address a methodological point by comparing the results obtained when asking students the same question in open and closed forms, i.e. to see if the responses received when students answered in their own words were different to those when they selected from a range of predefined responses. The second questionnaire was developed and submitted to students after writing the first paper, while the author was studying a statistics course for PhD candidates. The open question on students’ ideas for improving school chemistry courses from the first questionnaire was converted into a closed question with response options based on the answers students gave to the first questionnaire. There was a substantial difference in response rates to the two questions: only 65% of the students who completed the first questionnaire (which had the open question) suggested improvements whereas more than 99% of the participating students responded to the question when it was posed in a closed format. This suggests that students find it harder to give feedback and make suggestions when they have to express themselves in their own words. However, it is important to be aware of the limitations of fixed response options, which potentially allow the researcher to inadvertently guide the
thinking of the respondents. As such, the validity of a finding can be increased by using a combination of open and closed questions to obtain both high response rates and comparatively unbiased responses. Thus, a combination of both open and closed questions was a way to achieve a more valid result.

**Cognitive variables**

The students’ comments about connecting chemistry education to everyday life prompted an investigation into CBL approaches. Analysis of the CBL literature suggested that it would be important to examine students’ strategies when solving context-based chemistry problems. Since the design of chemistry tasks and assessments that will foster higher order thinking among students was one of the key challenges in CBL research identified by Pilot and Bulte (2006b), a pre-study was conducted to examine chemistry examination tasks and compare the responses of students and experts to a representative context-based task. The context and topic were chosen for their relevance, with the aim of provoking the students’ interest – the task had to do with Tamiflu (the drug used to treat swine flu) spreading in the environment, which was being discussed extensively in the media when the study was conducted. When working on the task, the students were provided with copies of a short newspaper article to demonstrate the relevance of the problem.

The pre-study revealed several methodological issues. Written responses provided only limited empirical information on the problem-solving process; in an interview situation, the interviewer can extract more information by asking follow-up questions. The questions students asked in the interviews, and the interviewer’s hints, comments or follow-up questions had profound effects on the students’ problem-solving processes. Analysis of the empirical data clearly indicated that guidance from the interviewer (or the teacher, as would be the case in typical school practice) influenced the students’ responses. It was also evident that a more systematically designed set of problems would be required in order to draw reliable conclusions about the problem-solving process. A third point raised by this pre-study is the importance of having a clear and structured design when developing tasks. Overall, the experience gained by conducting the pre-study highlighted the importance of a well thought-through planning phase. Consequently, when planning the main study, both the tasks and the interview process were designed using clearly articulated procedures and principles. The aim of the main study was to analyse students’ application of chemistry content
knowledge when solving context-based problems and to acquire more explicit insights into students’ problem-solving strategies and affective responses to the contextualisation of chemistry problems. The content areas examined in the pre-study (organic chemistry and chemical bonding) were also examined in the main study in order to facilitate comparisons between the two sets of results. The design process used in the main study was time-consuming, but appears to have been time-effective in hindsight.

Analyses of the students’ work on the problems set during the studies indicated that when presented with the structural formula of a chemical compound, they attempted to connect it to their chemistry content knowledge. Moreover, when supplied with a structural formula as part of a task, the students invoked chemistry concepts in their attempted solutions. The students’ responses can be analysed in terms of crosscutting disciplinary concepts (Sevian & Talanquer, 2014) and threshold concepts (Park & Light, 2009). For example, one of the problems required the students to discuss the solubility of a compound on the basis of its structure, which is an example of the crosscutting disciplinary concept of structure-property relationships. A threshold concept for understanding the relationship between structure and solubility is polarity and its relationship with electronegativity. If students had problems understanding the concept of electronegativity, they were unlikely to link the “∂+ and ∂−” hints offered by the teacher to the concept of polarity, and were therefore unable to link either of these concepts to solubility. By analysing individual content areas in terms of the crosscutting disciplinary concepts outlined by Sevian and Talanquer (2014), it is possible to identify fundamental threshold concepts that teachers must be aware of in order to effectively guide their students towards higher order thinking.

The HOCS/LOCS framework and the MHC-C both proved to be useful when analysing the students’ and experts’ written and oral responses, especially when applied in combination with the chemistry syllabus. All three build on Bloom’s ideas of hierarchical skills and complexity, and are therefore possible to combine. The proposed hierarchic nature of learning has been used explicitly in the teaching of chemistry by some researchers and challenged by others. Pungente and Badger (2003) used Bloom’s taxonomy in their teaching of introductory organic chemistry by showing students the hierarchy and helping them to move from lower levels of knowledge and comprehension towards learning through higher level cognitive processes. On the other hand, Zoller and Levy Nahum (2012) claim that there are significant differences between Bloom’s taxonomy and their own HOCS/LOCS framework, the most important being that higher order cognitive skills are non-linearly ordered, do not necessarily build on one-another, and overlap to varying degrees. Nevertheless, they agree that LOCS
are required to develop HOCS. The analysis presented in this thesis relies on two hierarchical frameworks - HOCS/LOCS and the MHC-C. Within such hierarchical frameworks, factual knowledge provides an essential foundation for higher order thinking despite not being sufficient for meaningful learning by itself. As previously mentioned, the crosscutting disciplinary concepts described by Sevian and Talanquer (2014), which include chemical identity and structure-property relationships, could potentially be useful for developing ways of teaching chemistry that promote higher order thinking among students.

To explore the problem-solving process, it was necessary to more extensively characterise students’ approaches to chemical problems and the strategies they adopted. In the main study, the students’ responses to the problem-solving tasks were recorded together with the interviewer’s scaffolding, making it possible to analyse the problem-solving process in terms of Hayes’ (1989) six problem-solving steps. The students did not generally perform the final two steps in Hayes’ sequence, i.e. evaluating the solution and learning from the experience. Because students tend to assume that there is a single correct answer that they must supply and are accustomed to completing tasks by recalling facts, the last two steps do not feature heavily in their problem-solving processes. Scaffolding based on the stepped supporting tools of Fach et al. (2007) and the MHC-C operators (Bernholt & Parchmann, 2011) helped the students to solve the assigned problems. However, in order for students to also learn about problem solving as a process and thereby develop their problem-solving skills, they must acquire an awareness of the individual steps of the process, especially the final two. Teachers must therefore highlight the process of problem solving and treat the development of problem-solving skills as a goal in its own right rather than focusing exclusively on the students’ responses to the chemistry task.

**Combination of affective and cognitive variables**

Some of the empirical data on problem-solving strategies and affective responses that were gathered during the main study were not reported or analysed in the fifth paper. These results are presented in this section. When analysing the contextualisation of the problems, it was obvious that the context had a positive affective effect, a result mentioned briefly in the fifth paper. All 20 participating students claimed that contextualisation makes tasks more interesting if it is possible to relate the problem to situations encountered in everyday life. They also all stated that tasks of the sort used in the study were not commonly encountered during upper secondary school
chemistry education, either in textbooks or during classes. A few students did mention having met similar problems in examination questions, but only as advanced challenges for students seeking the highest grades. This suggests that the participating students had little experience with chemistry problems designed to stimulate higher order thinking. When investigating interest and relevance, the students found it difficult to grasp the difference between the two variables. After the difference had been discussed and clarified, the students agreed that both the topics and contexts of the study’s 15 tasks were relevant. However, their reported levels of interest were more varied. Of the contexts, the personal was most interesting and the professional least interesting; the societal context was intermediate between the other two. This is consistent with previous studies, which highlighted the importance of allowing students to relate chemistry to themselves so that they could see the personal value of science (Bøe et al., 2011; Osborne & Dillon, 2008). All five topics covered by the study’s tasks were described as being interesting, but the most interesting topics were energy drinks and medical drugs. Because 20 students are too few to draw transparent conclusions from, additional data has recently been collected from 170 students, who were asked to solve the same tasks in writing and to write about their affective responses to the tasks. These results will be analysed and presented in upcoming publications outside of this thesis.

To characterise the students’ problem-solving strategies, both the students’ and the interviewer’s utterances were coded rigorously. Scaffolding was performed according to a protocol based on the stepped supporting tool technique (Fach et al., 2007) in combination with the MHC-C-operators name, describe, and explain (Bernholt & Parchmann, 2011); an example of the operators’ use is presented in the methodology section of paper 5. The students adopted different strategies in the early stages of the problem-solving process. Some quickly got started on their own, and gave responses without any input from the interviewer. In many cases, these students refined or elaborated upon their answers when asked clarifying follow-up questions by the interviewer. A different strategy was used when students had no idea where to start; often they said they were unfamiliar with open and broad problems whose solution required more than recall of facts. In such cases, the interviewer’s use of the MHC-C-operators was helpful in scaffolding the student’s problem-solving process and leading them to start identifying relevant factual points, describing the problem and relevant aspects of the material, and giving explanations. However, more detailed analyses of students’ problem-solving strategies will be required to clarify their use of contexts. Such analyses will be presented in future publications focusing on the relationship between problem solving and argumentation, students’ responses to questions with multiple plausible answers, and
methods for developing students’ skills of argumentation using open-ended questions. MHC-C operators may be useful tools for teachers to consider and use when attempting to scaffold the problem-solving processes of students who are inexperienced with higher order thinking.

Challenges and limitations

Clarifying the role of relevant prior knowledge is a key goal when investigating students’ problem-solving strategies for context-based chemistry tasks and the relationships of these strategies with higher order thinking and meaningful learning. No data on individual students’ prior knowledge were collected in this work. However, the author’s classroom observations and past experiences as an upper secondary chemistry teacher suggest that prior knowledge plays a fundamental role in problem solving and meaningful learning. In addition to prior knowledge, meaningful learning requires meaningful tasks, something that this thesis has tried to make clear. It is also important to present students with relevant and interesting tasks that satisfy their desire to connect chemistry to everyday life. The importance of relevance has been emphasised in the design of the context-based chemistry tasks. Finally, meaningful learning requires meaningful learning settings. All of the exploratory studies indicated that the working methods adopted in the chemistry classroom were meaningful settings, based on students’ responses to direct questions about their working methods and their open responses to questions about their chemistry education. The students also stated that they learn very well when the teacher plays a central role in the classroom and teaches chemistry in a thought-through and structured way. This result could be taken to indicate that students are lazy and only wish to be stuffed with information; student-centred methods demand more from the student, requiring them to take an active role in the learning process and to be responsible for their own learning. Another and perhaps a more realistic interpretation is that students enjoy different working methods, and each individual finds a combination of teacher-centred and student-centred methods valuable. However, since the students seem satisfied with different working methods, a combination of methods might be sufficient to achieve meaningful learning settings.

A parameter influencing the results presented in this thesis is the design of its constituent studies. Being a doctoral student means taking an educational journey to become a researcher, in other words an identity formation. In my case, this journey involved making a transition from being an educational
practitioner to being a researcher, something which was fundamental in the research process and is described in a book chapter outside of this thesis (Broman, submitted). A key process within this journey involved gradually developing an appreciation of the importance of carefully and rigorously planning studies, and of selecting a well-defined theoretical framework before performing empirical observations or analysis. Consequently, the final study (which resulted in paper 5) was planned with greater rigour and care than the first three (which resulted in papers 1-4). When evaluating the design and methodological issues of any study, it is important to consider the validity and reliability of its results. All of the studies included in this thesis used diverse sources of data (e.g. both written and oral records of students’ responses and remarks, responses to open and closed variants of the same question, classroom observations, and interview recordings), enabling triangulation. This increases the reliability and accuracy of their analyses and results.

One challenge for educational research highlighted by Treagust (2002) is the educational-political interface, i.e. the close relationship between education and politics. Even though science education research often asserts the need to change the formal curriculum, such changes are complex and time-consuming to implement in practice. Consequently, when changes are made, they generally involve modifying existing curricula. This makes it essential to discuss higher order thinking as something that is not merely important in terms of assessment; the results presented herein demonstrate that students are unfamiliar with chemistry tasks demanding more than recall of facts, highlighting a need for greater usage of tasks that require and develop higher order thinking skills (e.g. context-based chemistry tasks) within chemistry lessons. Only once students have had the ability to develop such skills during their studies should such problems be routinely included in assessments.

This thesis answers the following research questions: (1) What are Swedish upper secondary students’ opinions about their school chemistry courses, and what are their suggestions for improving the subject’s teaching? (2) Why do Swedish upper secondary students choose to study chemistry at the post-compulsory level, and how is this choice related to identity? (3) How do Swedish upper secondary students apply chemistry content knowledge when solving context-based chemistry problems? (4) What problem-solving strategies do Swedish upper secondary students apply when solving context-based chemistry problems, and how do their strategies compare to those used by chemistry experts? Overall, the results indicate that students have positive opinions of their chemistry education, would like to see a stronger connection between chemistry and daily life, prefer their education to involve a diversity of working methods, and consider the teacher’s
contribution to be essential for effective education. They have chosen to study post-compulsory chemistry mainly because it is needed for their future educational plans and because they enjoy science. Furthermore, their educational choice is evidently connected to the development of their identity; the dichotomy of ‘doing science’ versus ‘being a scientist’ has to be clarified, and even students who might be interested in doing science may require exposure to scientific role models in order to become scientists themselves. After studying students’ opinions on their chemistry education, their problem-solving strategies and use of chemistry content knowledge when confronted with context-based chemistry problems requiring the use of higher order thinking was investigated. The main finding of these studies was that students have little experience of higher order thinking and that their education is dominated by lower order thinking. School chemistry focuses too much on rote memorisation, leaving the most interesting aspects of chemistry unexplored and difficult for students to access. Factual knowledge is undeniably fundamental, and it is impossible to achieve higher order thinking without well-developed lower order cognitive skills. Nevertheless, the results presented herein suggest that a greater focus on higher order cognitive skills would be beneficial in chemistry education. This could be achieved by making more extensive use of relevant context-based chemistry problems to induce a paradigm shift from instructional practices based on the simple transmission of facts towards ones that promote higher order thinking and the development of problem-solving skills.
Conclusions

The Swedish upper secondary chemistry students who participated in this study generally held positive opinions about their studies, finding chemistry in general to be interesting. They also highlighted the importance of the teacher and the ability to relate chemistry to everyday life situations. The decision to study post-compulsory chemistry is mainly driven by students’ plans for their subsequent university studies, but identity and the students’ personal interests also affect their choices significantly. The role of identity was only examined briefly in this thesis and with a restricted and superficial focus, but is essential for understanding students’ affective responses to chemistry education. Even though chemistry as a subject is interesting, the students generally did not self-identify as scientists or chemists or people who might become scientists or chemists. This inability to see oneself as a scientist (among students who have chosen to study science!) may relate to the absence of appealing role models. The results of Ulriksen et al. (2010), which showed that students often regard female university scientists as negative role models may be important in this context. Can this picture of women in academia be changed? The expectancy-value model of Eccles et al. (1983) has been used as a lens to relate different affective variables to choices and course enrolment, and may merit further exploration in forthcoming studies on identity and its impact on student choice.

When exploring the processes by which students solve context-based chemistry problems, the characteristics of high quality tasks must be considered. To emphasise students’ higher order thinking skills, the tasks must require higher order cognitive skills such as the transfer of content knowledge, critical thinking and argumentation. Such HOCS-oriented examination tasks, which may be context-based to demonstrate relevance and arouse students’ interest, must be practiced repeatedly by students to enhance their higher order thinking. One suggestion given by Wickman is to study how “contexts could be made more supportive to conceptual learning within the model of contexts as practices” (Wickman, 2014, p. 152). The application of chemistry knowledge within relevant contexts or authentic practices is sensitive to both affective and cognitive variables. The ultimate goal is to increase students’ interest in chemistry and motivation to pursue a career in science while also developing their higher order thinking based on HOCS, potentially via the superordinate HOCS of knowledge transfer. A key goal of educational research is to promote learning and understanding for life, which requires students to exhibit more than just lower order thinking.
The data on the experts’ problem-solving processes demonstrate the importance of factual knowledge, without which it is impossible to discuss or argue about scientific issues at a high level of complexity. The problem with upper secondary school chemistry is that it almost exclusively emphasises recall of facts. To achieve a paradigm shift from LOCS-focused teaching to a focus on higher order thinking, Zoller and Levy Nahum (2012) argue that it will be essential to integrate HOCS-oriented problems throughout chemistry education, in assessment tasks, homework assignments and lesson tasks. Wider use of context-based chemistry tasks such as those used in this work would support a move towards this integration, but more open-ended conceptual problems must be designed and developed to help both students and teachers towards higher order thinking.

The students’ responses clearly indicated that competent and engaged teachers are important for good chemistry education. In addition to their affective value, the competent and engaged teachers requested by the students are crucial for enhancing students’ zones of proximal development. The scaffolding process requires a teacher who can use stepped supporting tools and thought-through hints (which may be structured according to the MHC-C principles) when assisting students in their problem solving to support meaningful learning be achieved. Teachers should be encouraged to practice giving such hints and developing their classroom dialogues to assist the development of students’ problem-solving skills.

**Implications**

The results presented herein have several important implications. The first is that meaningful learning should be given a more prominent position in school chemistry education at multiple levels. Factual knowledge is unquestionably essential, but developments in Information and Communication Technology allow students to access such knowledge via their computers or smartphones far more quickly than was the case when it was necessary to search through textbooks or handbooks of formulae. Therefore, it is increasingly important for students to practice interpreting and applying factual knowledge in new learning situations, and transferring content knowledge from one learning situation to another; chemistry classes should focus more on the development of such skills. To achieve such changes in school practice, teacher education and in-service teacher training programmes must emphasise meaningful learning through higher order thinking. If university courses for prospective teachers continue to focus on factual knowledge from limited content areas, teacher students will not ever
see the bigger picture discussed in the train metaphor given by Osborne and Dillon (2008), which was mentioned at the start of this thesis. Moreover, if we want school students to develop higher order thinking skills, it will be essential to teach students how the skills can be developed; as Cook et al. put it, “if students have never been explicitly taught that there is more to learning than memorization, they have no way of knowing how to develop higher-order thinking skills” (Cook et al., 2013, p. 966). These authors conducted a successful intervention with college chemistry students and implemented a Study Cycle related to Bloom’s taxonomy with the aim of introducing metacognition as an important aspect of learning. This kind of study cycle where students are explicitly taught how to work on their own learning processes could potentially be a viable way of improving students’ higher order problem-solving skills in chemistry.

Besides making students aware of higher ordering thinking, one way to practice such skills is through reasoning and argumentation; when students develop their argumentation skills, they also challenge their thinking. For argumentation to be rewarding, it must rely on both facts and higher order cognitive skills as transfer, critical thinking and asking questions. Problem-solving strategies in general should be discussed in school; students should be aware of and practice their solving skills rather than just focusing on the content outcomes arising from the problem-solving process. Hayes’ (1989) six problem-solving steps could be useful in making students explicitly aware of their solving processes rather than focusing exclusively on the results. Another potential way of increasing students’ awareness of higher order thinking would be to introduce context-based tasks that require higher order thinking into the classroom, for example via chemistry textbooks. Since Overman et al. (2013) have stressed the absence of relevant and meaningful tasks in both context-based and conventional chemistry textbooks, it will be necessary to design and develop new higher order tasks for this purpose. This could conceivably be done using the design principles outlined in paper 5. However, it is important to note that the main aim is to encourage students to challenge their learning processes and develop their higher order thinking, not specifically to incorporate CBL into formal curricula. It is always important to recall that “Teaching is a complex transactional process that cannot be fully reconstructed from official documents, research or planning but depends on what happens in the classroom” (Wickman, 2014, p. 147).
Outlook

The results and analyses presented in this thesis raise several issues that warrant further action and investigation. First, some of the empirical data gathered during the main study have yet to be published and explored. The two affective variables of interest and relevance need further clarification, as noted by Stuckey et al. (2013). This issue has been investigated (although the resulting data have yet to be analysed) in a follow-up to the main study featuring 170 participating students. These students were asked to solve the 15 context-based tasks from the main study in writing, and to describe their affective responses to each one (i.e. their perceptions of each task’s interest value, relevance and difficulty). It will be interesting to analyse these empirical data in conjunction with the transcripts of student interviews from the main study.

Besides these problem-solving aspects, in the beginning of these interviews before the students attempted to solve the context-based chemistry problems, the 20 students were asked why they had chosen to study the NSP at the upper secondary level. One common response was that the students wanted to become medical doctors; when asked why they wanted to be doctors, the students cited the generally positive perception of doctors. That is to say, doctors were perceived as good role models. Furthermore, when asked about why medical doctors were perceived as good role models, almost everyone gave one specific and somewhat astounding example (among other examples): the TV show Grey’s Anatomy. Could it be that Dr Shepherd and Dr Grey are important role models for Swedish upper secondary students? And if so, are there any positive role models for chemistry in particular? One possible method for analysing interest related to educational choices is the RIASEC personality type model (Dierks et al., 2014; Holland, 1963). It would be interesting to use this model to examine the relationships between interest, identity, role models, and educational choices. In addition, the relationship between students’ in-school and out-of-school activities should be investigated; as shown by Dierks et al. (2014), these activities can have divergent effects on students’ interests. The influence of role models, both within school and in society as a whole, should be explored using tools such as the expectancy-value model (Eccles et al., 1983).

Regarding cognitive aspects, both the problem-solving strategies mentioned in the result section should be explored further to study how students address new unfamiliar open-ended conceptual problems, and how teachers, through scaffolding can help students to achieve higher order thinking and meaningful learning. The written responses gathered during the follow-up to the main study will be used to examine students’ responses to context-based
problems solved without any assistance from teachers or an interviewer. Hopefully, the resulting empirical data will facilitate the development of robust and well-defined tools that teachers will be able to use to challenge students’ thinking and allow them to understand their own learning processes, thereby inducing a paradigm shift from being taught to learning how to think (Zoller & Levy Nahum, 2012). Finally, it should be noted that the participating students’ prior knowledge was not investigated in this thesis. As such, it is not clear how much meaningful knowledge each student possessed before attempting the context-based problems, which may limit the general applicability of the conclusions drawn. This point should be investigated further in future.

This thesis has a clear student focus; the starting point was a study on students’ opinions relating to their chemistry education and students’ learning outcomes in chemistry. Complementary teacher-oriented studies, possibly using practical epistemology (Wickman, 2014), could provide a more comprehensive picture of students’ learning progressions. Teachers will have an important role to play if CBL and higher order thinking are to be introduced in schools, and variables such as their epistemological beliefs may have a significant impact. On the basis of Dutch studies on the implementation of CBL approaches, Stolk et al. (2009a, 2009b; 2011) assert the need to empower teachers with strategies to make the changes needed to develop and improve school chemistry. The importance of teachers in the provision of good chemistry education was highlighted by the students examined in this thesis, which makes it fitting to conclude with a quote from Jean-Jacques Rousseau’s book ‘Emelie or On Education’ from 1762; “The issue is not to teach him the sciences but to give him the taste for loving them and methods for learning them when this taste is better developed”. The upper secondary students, obviously both “him” and “her”, investigated in this work apparently already have a better developed taste for science, meaning that their teachers mainly require methods that will help them to learn chemistry in a meaningful way.
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Presentations

Peer-reviewed conference presentations of my PhD project:


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