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Students' application of chemical concepts when solving chemistry problems in different contexts

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Abstract

Context-based learning approaches have been implemented in school science over the last 40 years as a way to enhance students' interest in, as well as learning outcomes from science. Contexts are used to connect science with the students' lives and to provide a frame in which concepts can be learned and applied on a 'need-to-know'-principle. While effects on interest are coherently reported as positive, they are more diverse regarding cognitive learning outcomes. Hence, the demand for further research on criteria of context-based problems and problem-solving processes has been stated. In this paper, a study is presented investigating students' application of chemical concepts when solving context-based chemistry problems. Tasks for context-based problem solving have been designed systematically, using different combinations of contexts, topics and chemistry concepts in relation to the syllabus. Empirical data were collected using think-aloud interviews where 20 upper secondary students used their chemical content knowledge to solve the problems. The 15 context-based problems raised challenges within organic chemistry where concepts like electronegativity, polarity and solubility had to be applied. The difficulty to differentiate between intra- and intermolecular bonding emphasised in earlier research has also been apparent in this study. Besides the structural formula, which was an important part for the students when solving the tasks, the contextualisation of the problems was often used in the responses; students related their answers to the personal, societal or professional context in different ways. The paper explores the results and gives implications for context-based teaching, learning and assessment.

Key words: *context-based chemistry, problem solving, upper secondary students, think-aloud interviews, organic chemistry*

Introduction

Context-based learning (CBL) approaches have had a strong influence on school science in several countries as a way to both stimulate students' interest and motivation, and to provide more interconnected content knowledge (Bennett, Lubben, & Hogarth, 2007; King, 2012; Nentwig & Waddington, 2005). Literature reports positive effects on students' interest and motivation (Bennett *et al.*, 2007; Fechner, 2009), while the impact of CBL on students' cognitive learning outcomes are less coherent (Fechner, 2009; Taasobshirazi & Carr, 2008). The theoretical background of CBL approaches, for example the German 'Chemie im Kontext', is based on the framework of scientific literacy, and theories on interest, motivation and situated learning (Nentwig, Demuth, Parchmann, Gräsel, & Ralle, 2007). According to Nentwig *et al.* (2007) scientific literacy is perceived as an intersection of knowledge, activities and values. Students motivation and interest are, as mentioned above, one of these approaches' benefits,

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3 students often find context-based chemistry more interesting and motivating than conventional
4 approaches (Bennett *et al.*, 2007; King, 2012). Since outcomes regarding the cognitive results of
5 CBL are more diverse, Pilot and Bulte (2006) highlight critical aspects important to take into
6 account for the design of CBL approaches; for example the development of suitable assessment,
7 the design of adequate tasks, and the analysis of students' responses to these tasks. These critical
8 aspects are obviously not limited to CBL, still this argues for a more systematic analysis of task
9 criteria and problem-solving processes. As context-based problems combine chemistry content
10 with contexts to make the problem more authentic and relevant, they ask for complex thinking
11 and higher levels of scientific literacy (Hofstein, Eilks, & Bybee, 2011). Therefore the aim of this
12 study is to systematically design context-based problems in demand of higher order thinking
13 where students' responses are systematically analysed. As a consequence, when designing the
14 problems, there have been explicit and intentional starting points regarding both context and
15 content to make it possible to scrutinise how these two parts influence students' responses. The
16 design process of 15 tasks emanated from a pilot study (Broman, submitted; Parchmann,
17 Broman, Busker, & Rudnik, submitted) highlighting the importance of a structured design of
18 topic, context and content. Students' responses were collected using semi-structured interviews
19 with think-aloud techniques to get an in-depth qualitative insight on students' chemistry
20 explanations and how they apply chemical concepts in context-based chemistry problems to give
21 implication on teaching and assessment of school chemistry.
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31 Background

32 Chemistry education in Sweden

33 Since the study was carried out in Sweden the educational background needs to be described as a
34 frame for the study. In Sweden, the upper secondary chemistry syllabus is not explicitly context-
35 based, as in several other countries (*e.g.* Germany, the Netherlands, UK, US) and chemistry
36 textbooks, which are described as the foundation for teaching (Bergqvist, Drechsler, de Jong, &
37 Chang Rundgren, 2013), are more conventional. Previous Swedish research also highlights upper
38 secondary chemistry teaching emanating from the textbook and with a clear emphasis on basic
39 definitions and symbolic representations (Adbo & Taber, 2014). However, connection to
40 everyday life is requested by Swedish upper secondary students to improve school chemistry to
41 make it more meaningful (Broman, Ekborg, & Johnels, 2011; Broman & Simon, submitted). This
42 connection to everyday life can be translated into the prospect for CBL approaches
43 foregrounding this study. Even though there is no explicit context-based syllabus in Swedish
44 schools, it is not possible to predict how individual teachers teach chemistry and if the school
45 chemistry students meet might be context-based. Sjöström (2013) concludes that chemistry
46 teachers often try to connect the content with everyday life, however not in a critical way without
47 problematizing the relationship between everyday life and the chemistry content. The notion of
48 'everyday life' is mentioned in the first sentence of the syllabus valid at the time of this
49 investigation; "The subject of Chemistry aims at providing an advanced understanding of
50 chemical processes and a knowledge of the variety of chemical applications and their importance
51 in everyday life, industry, medicine and the living environment" (Swedish National Agency for
52 Education, 2000). This makes it important to ask students how familiar they are with these
53 approaches, in this case, regarding chemistry tasks that are context-based.
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Context-based learning approaches

The meaning of 'context' has been scrutinized from various perspectives, both concerning the notion in general (van Oers, 1998) and within context-based learning (CBL) approaches (Gilbert, 2006; Gilbert, Bulte, & Pilot, 2011). A useful definition applied in several approaches is that the context "is the red thread along which the investigation of the issue in question develops" (Nentwig *et al.*, 2007, p. 1441), not only a mere decoration in the beginning or in the end to illustrate something or motivate students. The context is the starting point from where the teaching proceeds, and the ground principle is that the learner will start off from the context and then be aware of the content knowledge in demand to understand the issue in question on a 'need-to-know'-principle (Bulte, Westbroek, de Jong, & Pilot, 2006). The relationship between a context and the subject-matter concepts can have varying characteristics; contexts can illustrate concepts, contexts can be used as an application of a concept, and contexts can be seen as a starting point from where teaching can emanate (de Jong, 2006). Nevertheless, the distinction between context and content is not always clear (Häussler, Hoffman, Langeheine, Rost, & Sievers, 1998; Pilot & Bulte, 2006), *e.g.* topics like fuels or food are sometimes named contexts while elsewhere, a personal or a societal framing for such topics are defined as contexts. As a consequence, words like topic, context, modules (Graeber & Lindner, 2008), and themes (Nentwig *et al.*, 2007) sometimes imply the same, sometimes something different. In this study, we have made a clear distinction between the topic regarded as the broad area connected to everyday life, *e.g.* health, food and fuels; whereas the context is the setting in which the topic is displayed, *i.e.* personal, societal or professional. Bulte and colleagues (2006) have emphasised the use of this kind of authentic practices to enhance the relevance of learning about chemistry.

New and more unconventional teaching approaches like CBL sometimes get critique for concentrating primarily on engaging students by showing authentic practices that are found relevant, at least from the perspective of the teachers, researchers and textbook authors. Sevian and Talanquer (2014) maintain the need to be aware of the importance of the chemical concepts, not only the context part, where they assert that "in some cases core chemistry ideas and practices get buried under the specific contexts used to motivate and drive learning in the classroom" (Sevian & Talanquer, 2014, p. 2). Furthermore, Marks and Eilks (2010) also challenge context-based chemistry education by claiming it sometimes to be superficial, arguing that contexts not automatically motivate students, and that reflection has to be made when developing these new approaches. Therefore, in this study the chemistry content knowledge is the foundation; the context-based tasks have been designed with chemistry content areas and their concepts as first consideration, the interviews have been conducted by a researcher with upper secondary chemistry teacher experience, and students' responses have always had a clear chemistry focus in the analysis process. Unquestionably, both affective and cognitive parts are intertwined and important to investigate in parallel, hence students' perceived interest for and perceived difficulty of the tasks have also been monitored and will be mentioned briefly here, however analysed further in upcoming publications. The choice to inquire upper secondary students at the Natural Science Programme was also deliberate to emphasise the chemistry content; with older students there are more concentration on the subject itself, and also since this is a programme preparing students for chemistry studies at university level.

Several research projects investigating CBL approaches have been accomplished over the last 40 years and as mentioned earlier, previous results show mainly positive affective effects whereas the cognitive effects are more complex to draw conclusions from (Bennett *et al.*, 2007;

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King, 2012; Ramsden, 1997). Most research was conducted in countries where full context-based curricula are implemented or where new teaching units are possible to use. In Australia, using the theoretical framework of Vygotsky's sociocultural perspective in combination with Bourdieu's notion of field, King and Ritchie (2013) have been investigating the links successful students make between concepts and context in an inquiry task on water quality of a local creek. In the Netherlands, Overman *et al.* (2013) have analysed textbook tasks from both context-based and traditional curricula highlighting the orientation towards traditional chemistry content in the questions from both curricula and although CBL chemistry relates tasks to societal and professional issues, there was not much emphasis on higher order learning. In Germany, Marks and colleagues (2008; 2010) have developed lesson plans on shower gels and potato crisps from a socio-critical starting point, claiming a potential for higher order thinking skills and meaningful learning. The aforementioned 'Chemie im Kontext' is another teaching approach developed and implemented in Germany with modules tested both by secondary teachers and researchers (Nentwig *et al.*, 2007; Parchmann *et al.*, 2006). Since the Swedish chemistry syllabus has no explicit CBL approach, it has not been possible to implement and investigate full teaching units. However, we believe that parts of CBL approaches can be applicable without a full curricula change, making it possible to apply context-based chemistry problems as student tasks without the teaching approach, as these problems in themselves demand the same level of chemistry as the tasks found in upper secondary chemistry textbooks. The benefit of using these problems might be a movement to make school chemistry more relevant for students, a request from both students and teachers, as well as researchers (Nentwig & Waddington, 2005). Another example to implement parts of CBL approaches has been suggested by Christensson and Sjöström (2014) who have analysed on-line thematic chemistry videos from the International Year of Chemistry presenting chemistry in context, where they show a clear message of chemical literacy, a foundation for CBL approaches. In the outlook of this paper we will discuss how parts of a CBL approach, for example context-based tasks, can be applied in chemistry education in a meaningful way even though the curriculum has no explicit context-based focus. This is the opposite of other previous projects where students meet context-based teaching and textbooks whereas their examination tests are more conventional (Bennett *et al.*, 2007).

43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 **Chemical explanations and scientific literacy**

When investigating students' problem solving of context-based chemistry tasks, the framework of scientific literacy is foregrounding the design process of the problems by developing the tasks with relevant concepts in varying topics and contexts. CBL approaches are not exclusive in relating the framework to scientific literacy; *bildung*-oriented chemistry education (Sjöström, 2013), socio-scientific issues (Sadler & Zeidler, 2009), and humanistic learning approaches (Aikenhead, 2006) are examples of other learning approaches with the joint goal of scientific literacy. Moreover, the PISA project assesses scientific literacy highlighting its emphasis on today's science education (Bybee, McCrae, & Laurie, 2009). The notion of scientific literacy is a broad expression with composite meaning and is often perceived as the general purpose of science education. By relating to Roberts' (2007) two emphases of scientific literacy, *i.e.* Vision I and II, the starting point for CBL approaches is Vision II, stressing science in everyday life situations in which science plays a key role. These two visions of scientific literacy are, as Roberts stated, representing two "extremes" on a continuum. Therefore, in this study we explore students' application of chemistry concepts when solving context-based problems making it

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3 central to consider both Vision I, emphasising the science subject matter itself, in combination
4 with Vision II.
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6 To analyse students' application of chemistry concepts in their responses to context-based
7 problems demands elaboration of what kind of content knowledge these problems require and
8 how we interpret chemical explanations. Taber and Watts (2000) have studied the quality of
9 students' explanations when solving chemistry problems stating three key parameters to consider
10 when valuing the responses to be explanations or not, *i.e.* if the response has the structure of an
11 explanation by stating words like 'because' and 'therefore'; if the response is logically consistent;
12 and if the response is correct or not. A foundation for chemical explanations are students' ideas
13 about which parts are important to give as a response, in other words what they are used to meet
14 in chemistry education. Smith (2011) highlights the importance of relevant and meaningful
15 learning settings, and claims that the engagement is a crucial factor for successful education.
16 Nevertheless, rote learning has for many years been the foundation for school and university
17 chemistry, where teaching emphasises formal definitions, equations and rules, and where students
18 often get the impression that there is always only one correct answer to every question (Zoller &
19 Pushkin, 2007). School chemistry in most countries has focused rote learning of isolated topics
20 with their concepts and ideas, for instance atomic structure, chemical bonding and
21 thermodynamics (Sevian & Talanquer, 2014). Rote learning has a clear relationship with lower
22 order thinking, for example rote memorization and recall of factual knowledge, which contrasts
23 the idea of context-based authentic problems that ask for complex and higher order thinking.
24 Higher order thinking needs to be learned and trained and therefore students have to meet
25 different kinds of tasks, not only textbook tasks focusing on recall of facts (Bergqvist *et al.*, 2013;
26 Overman *et al.*, 2013). Unquestionably, there is an obvious need for factual knowledge in solving
27 context-based problems; however, the idea here is to not *only* focus on recall of facts. Higher
28 order thinking relates to meaningful learning by applying non-algorithmic, complex problems
29 with multiple solutions that involve application of multiple criteria and uncertainty (Dori, Tal, &
30 Tsaushu, 2003; Zohar, 2004; Zohar & Dori, 2003). Context-based chemistry problems, referring
31 to the goals of scientific literacy, ask for complex thinking when solving the tasks, and is a
32 feasible way to train students to give structured explanations and apply higher order thinking
33 since the problems themselves make it apparent for students that there is not only one single
34 correct answer to every chemistry problem; instead, many different solutions are often
35 conceivable. Many different possible solutions are one central aspect for context-based chemistry
36 problems and we believe this to be an important change for school chemistry (at least in some
37 countries), to make the subject more trustworthy and understandable.
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50 **Chemistry problems and concepts**

51 Problem solving has been a significant aspect investigated within science education research for
52 many years (Bodner & Domin, 2000; Bodner & McMillen, 1986; Cartrette & Bodner, 2010;
53 Nakhleh & Mitchell, 1993; Ngu & Yeung, 2012). A prevailing definition of a problem within
54 science education has been claimed by John Hayes "Whenever there is a gap between where you
55 are now and where you want to be, and you don't know how to find a way to cross that gap, you
56 have a problem" (Hayes, 1989, p. xii). It is the second half of the definition that distinguishes
57 problems from exercises, in other words, how familiar the task is. Exercises are solved on
58 routine, whereas problems are novel and demand more from the solver (Bodner & McMillen,
59 1986). To demand more, other competencies than recall of facts are needed; the "success in
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3 solving algorithmic problems does not indicate mastery of the relevant chemical concepts”
4 (Zoller & Dori, 2002, p. 187). Within context-based chemistry, Gilbert highlights the importance
5 of “problems that are clear exemplifications of chemically important concepts, to enable learners
6 to develop a coherent use of specific chemical language” (Gilbert, 2006, p. 970).
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9 The syllabus (Swedish National Agency for Education, 2000) is framing the course content,
10 showing which competencies students are supposed to develop during the course. Different
11 content areas are presented in the chemistry syllabus, for instance stoichiometry, acids & bases,
12 redox, organic chemistry, and biochemistry. Regarding organic chemistry, there is an apparent
13 connection to chemical bonding, especially to hydrogen bonds since many organic compounds’
14 properties can be explained by this kind of intermolecular bonding (Henderleiter, Smart,
15 Anderson, & Elian, 2001). For a long time, chemical bonding has been explained through several
16 diverse models building on physical principles generating alternative conceptions, and even
17 misconceptions, producing learning impediments for students (Taber & Coll, 2002). Students
18 often highlight anthropomorphic explanations for why bonding occurs, for instance that atoms
19 want, need, or search for something and that the ‘octet rule’ is aimed for (Adbo & Taber, 2013;
20 Levy Nahum, Mamlok-Naaman, Hofstein, & Taber, 2010; Taber & Coll, 2002). Thus, the ‘octet
21 rule’ has often been regarded as a valid foundation for bonding, thereby making it difficult to
22 explain how, for example, sulphur and phosphorus atoms can take part in covalent bonds (Levy
23 Nahum *et al.*, 2010). As a result from preconceptions like this, research recommend a change
24 from the more traditional view on bonding into a new teaching approach of chemical bonding
25 (Levy Nahum, Mamlok-Naaman, Hofstein, & Krajcik, 2007). This new bottom-up framework
26 suggested by Levy Nahum and colleagues (2007; 2008; 2010) relies on concepts like atomic
27 energy levels, Coulomb’s law and electronegativity giving a coherent understanding of all types of
28 chemical bonds. In Swedish textbooks and in chemistry classrooms, the traditional view on
29 bonding is prevalent (Adbo & Taber, 2014; Bergqvist *et al.*, 2013), dividing bonding into two
30 distinct groups; *i.e.* intra-molecular bonds with ionic bonding and covalent bonding, and
31 intermolecular bonds with dipole-dipole-bonding, van der Waals forces and hydrogen bonding.
32 This traditional view makes it interesting to investigate how Swedish students apply chemistry
33 content knowledge on chemical bonding in this study’s context-based tasks that are demanding
34 more complex reasoning regarding chemical bonding.
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37 In summary, context-based problems have the potential to expose the higher order
38 thinking by asking not only for one single correct recalled answer, but instead ask for different
39 conceivable solutions. However, empirical results show different outcomes so far. More research
40 is required on how and when students apply chemistry explanations based on higher order
41 thinking to solve context-based problems successfully and thereby fulfil requirements of the
42 educational framework of scientific literacy. The rationale of our project is to develop a structure
43 for the systematic design and analyses of context-based problems and analyses of students’
44 responses. In this paper the chemistry content knowledge given in the responses according to the
45 different contexts will be explored, whereas the problem-solving process will be scrutinised in a
46 forthcoming paper. The research questions investigated in this study are: (1) How do upper
47 secondary students apply their chemistry content knowledge when solving context-based
48 chemistry problems? (2) Which misconceptions of chemistry content can be revealed when
49 students solve these problems? (3) How do students make use of the contextualization of the
50 task into topics and contexts given in the problems?
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Methodology

This study was carried out in Swedish upper secondary schools (school year 10-12) in the Natural Science Programme (NSP). Students choose themselves what programme they want to attend and the NSP is regarded as the programme for the “future scientist”. However, even though most students choose this programme because of prospects for higher education (Anderhag, Emanuelsson, Wickman, & Hamza, 2013; Broman & Simon, submitted) and most of them also continue to university studies after this programme (SCB, 2012), not everyone aims for tertiary science or chemistry. Still, at the programme chemistry is studied to the highest upper secondary level to prepare for higher education within chemistry. The choice to investigate this population, students that can be seen as the “future scientist”, was deliberate since the chemistry content is focused more at upper secondary level when compared to compulsory school (purposeful sampling). In this study, we wanted to explore how students who have chosen to read as much chemistry as possible at this level apply their chemistry content knowledge when solving context-based chemistry problems. Therefore, we inquire students’ responses to context-based problems, not exercises. 15 context-based tasks representing less pre-structured and more complex conceptual problems to the students (Salta & Tzougraki, 2011) have been designed and developed.

Systematic design of context-based problems

To scrutinise both affective and cognitive challenges with context-based problems, the design of the tasks has been made thoroughly. In a pilot study, ten context-based problems were designed and from this, one exemplary task was studied in-depth to elaborate an analytical framework possible to use both for analysis of the context-based tasks in themselves as well as students’ response and process when solving the tasks (Broman, submitted; Parchmann *et al.*, submitted). The pilot study highlighted the apparent need for a more systematic design process where both the content for the tasks as well as the structured development of the tasks have to be carefully considered. Regarding the content for the tasks, results from an exploratory study (Broman *et al.*, 2011) on students’ perception of their school chemistry have been applied. For one content area, chemical bonding, students and teachers did not agree on how difficult this was for the students. The students claimed that chemical bonding was quite easy whereas their teachers asserted the content area to be difficult for students. This difference in opinion might be explained by students’ unconsciousness about the complexity of chemical bonding. Nevertheless, chemical bonding is a fundamental content area to understand relevant and authentic topics like medical drugs and food. The content is regarded as the chemistry area with its concepts, *e.g.* in the content area of chemical bonding there are concepts of for instance electronegativity and polarity. The content areas are areas stated in the syllabus (Swedish National Agency for Education, 2000) as well as being chapters in the chemistry textbooks used by the students in this study (Andersson, Sonesson, Svahn, Tullberg, & Rydén, 2008; Henriksson, 2007). These distinctions between topic, content and context needs to be considered when designing new context-based tasks as well as when investigating students’ opinions about these problems to understand which parts of the task that explicitly affect students’ opinion and influence students’ problem solving.

With regard to the structured development of the tasks, 15 context-based problems were thus designed with four explicit starting points. First, considering content area for the reason given above, organic chemistry in relation to chemical bonding was chosen, for example

problems asking for different organic compounds' solubility. Second, regarding topics, five different topics were selected from results originating from the Relevance of Science Education (ROSE) study (Jidesjö, Oscarsson, Karlsson, & Strömdahl, 2009; Sjöberg & Schreiner, 2010). The topics were medical drugs, energy drinks, fats, fuels, and soaps & detergents. Three of them were chosen since they are appreciated by students according to the ROSE study, *i.e.* medical drugs, energy drinks and fats (in relation to health and food); the topic of fuels was chosen because it is a common area used in context-based courses (*e.g.* Demuth, Parchmann, & Ralle, 2006); and the topic of soaps & detergents was chosen since conclusions are drawn from the ROSE study that students do not appreciate everyday life because they do not value this specific topic (Sjöberg & Schreiner, 2010). Third, the five topics were thereafter framed by three different contexts; a personal, a societal and a professional context (de Jong, 2006). This choice was made to investigate if it is the contextual setting of each topic that affects students' opinion about the problems. Finally, all tasks had two or three structural models included, mainly to accentuate the chemistry focus. An overview of all five topics and their related content areas and molecular structure is presented in table 1.

Table 1. Overview of the five topics and their content areas with concepts and molecular structure.

Topic	Content areas and concepts	Molecular structure			
Medical drugs	Solubility, polarity, bonding, size, acids/bases	Paracetamol, acetylsalicylic acid, ibuprofen			
Energy drinks	Solubility, polarity, bonding, size, acids/bases	Caffeine, taurine			
Fats	Structure, bonding, size, solubility	Palmitic acid, oleic acid, linolic acid			
Fuels	Structure, combustion, energy, size, bonding	Octane, heptadecane, ethanol			
Soaps & detergents	Solubility, polarity, structure, size, acids/bases	Oleic acid, lauric acid			

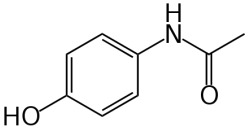
The design process was an iterative process between the English and Swedish languages since the interviewed students had to meet the problems in Swedish whereas the research process and analysis have been carried out in English, hence the wording of the tasks was thoroughly considered. The tasks were not supposed to give clear hints on content areas possible to use and to avoid using chemistry words, the tasks were presented to the students in Swedish using more everyday words in a way that made sense in Swedish. However, the literal translation of the tasks into English, which is presented in figure 1 with the three contextualized tasks on the topic of

medical drugs, includes words that would not be used in the same way if the task was presented in English. To give example on what these are, we use the word 'mix' and 'spread' instead of 'dissolve' and 'solubility' in the three tasks in figure 1. It was also important that the text was not too long and complex in the tasks since we wanted to avoid reading comprehension influences.

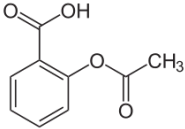
A. Personal context
 When you take a medical drug, it has to mix in your blood to be transported in your body. Blood consists mainly of plasma, which is made mostly of water. When you have a headache, there are several different medical drugs on the market, for instance Alvedon, Treo and Ipren. To get a quick reaction and to get rid of the pain, it is important that the drug molecule mixes in the blood. What makes these medical drugs spread in the blood?

B. Societal context
 When medical drugs are used in society, there are always effluents in the environment, partly from the surplus from drugs taken by humans, partly from industries when producing the medical drug. What chemical properties do these headache drug molecules (for instance Alvedon, Treo and Ipren) have that will make them spread in the environment?

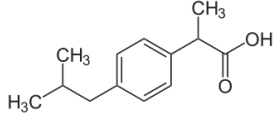
C. Professional context
 Chemists at medical drug companies have to design, develop and produce molecules that give the requested effect and also are mixed quickly in the blood to be effective. There are several drugs against headache on the market, for instance Alvedon, Treo and Ipren. When looking at these three molecules, there are differences but also similarities. Which parts of the molecule do the chemists have to consider regarding how the molecules are spread in the body?



Paracetamol/Alvedon



Acetylsalicylic acid/Treo



Ibuprofen/Ipren

Figure 1. Examples of context-based problems, topic: medical drugs. Literal translation of the tasks from Swedish to English.

To validate the chemistry problems, an interview with a university chemistry professor was accomplished before the students met the tasks. His response was asked to be as broad as possible, to become aware of all possible solutions to the problem. He also had the opportunity to give comments on the tasks to improve them. Besides this, two upper secondary teachers looked at the problems to validate the level of chemistry being suitable for upper secondary school students.

Project design, participants and interview guideline

To explore students' applied content when solving context-based chemistry problems, semi-structured interviews with think-aloud techniques were carried out with 20 students from three different schools. The choice to use interviews instead of students' written responses as in one part of the pilot study (Broman, submitted) was to get in-depth insights on both affective and cognitive parts of CBL approaches and to explicitly investigate the process of problem-solving. The students (aged 18-19 years-old) were in the end of their chemistry schooling at upper secondary level, and were chosen to solve the context-based tasks. They had completed the two

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3 chemistry courses possible to take at the NSP in Sweden. The students could thereafter apply for
4 university studies to become for instance medical doctors, engineers or scientists. The students
5 came from three different schools having different teachers, as a way to minimize teacher effects.
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7 All students participated voluntarily, the first contact was taken through the three teachers
8 who gave suggestions on students they thought were willing to participate. The request was
9 students who could take time to do the interview and orally could explain how they think when
10 they solve problems. The students were assessed by their teachers as medium- to high-achievers.
11 The first author contacted the students and informed them about the project. Moreover, the
12 teachers also shared the examination test the students had conducted within their chemistry
13 course, as a way to compare their ordinary tasks with these context-based problems. The
14 interviews were made in Swedish at a place chosen by the individual student, often out-of-school,
15 and lasted about 45-50 minutes each. Every student encountered six tasks, *i.e.* two topics in three
16 contexts, and was at first asked how these problems resembled tasks they meet in school
17 chemistry. Regarding the cognitive parts, students solved two tasks, after choosing one context
18 each from both topics.
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20 In the interviews, students always started the problem-solving process on their own,
21 without interference from the interviewer. This was a way to investigate what students come to
22 think about initially. After the students had had the opportunity to express their ideas, the
23 interviewer proceeded by giving hints and asking clarifying questions. If the student gave a broad
24 and extensive answer, clarifying questions were posed, whereas hints were given to students who
25 might elaborate their answers more. The hints were given according to the analytical framework
26 of the Model of Hierarchical Complexity in Chemistry, MHC-C (Bernholt & Parchmann, 2011)
27 which was a helpful analytical tool previously piloted (Broman, submitted; Parchmann *et al.*,
28 submitted), and where the MHC-C-operators “name, describe, explain” were used to structure
29 the hints. To be aware of the solution process and the order and structure of the hints, Fach *et*
30 *al.*'s (2007) different stepped supporting tools was used as a technique. When students solved the
31 problems, they used correct, incorrect and incomplete strategies and depending on strategy,
32 different tools were given by the interviewer. This well-reasoned hinting in the interviews was an
33 evident result from the pilot study where it was clear that leading questions and hints affected
34 students' responses (Parchmann *et al.*, submitted). In addition, previous research proposes use of
35 structuring or focusing strategies to foster deeper thinking and not only simple recall, in other
36 words, to use stimulus like for instance tables or formula from which questions are based (Chin
37 & Brown, 2002).
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39 After five interviews, it was apparent that the students at first always concentrated on the
40 structural formula when answering, not noticing the contextualization of the task. As a
41 consequence, a decision was made to make a slight change in method and not present the
42 structural formula in the beginning of the interview, instead making students solve as much as
43 possible without the formula and thereafter show the formula as a hint. This change of method
44 have been noticed when doing the analysis and this different circumstance will mainly be
45 discussed when presenting the results on how the contextualized part affects students' responses.
46 Transcription was made after listening to the interviews, and two months after transcription, the
47 interviews were re-listened and adjusted. Translation from Swedish to English was made in the
48 transcription process to make it possible for the co-author to contribute in the analysis process
49 and enhance inter-rater reliability.
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Two exemplary excerpts will be presented here to get an insight about the interview method in relation to the process of problem-solving. The interview process differed between students who were reluctant to elaborate their response, similar to the study of Fach *et al.* (2007) where several students used only incomplete strategies to solve the problem, and students who solved most of the problem themselves. The less able students needed several hints to solve the problems, for instance general strategic, content-strategic, content-related stepped supporting tools (SST) or by giving students general glossary of important terms. The general strategic SST are hints to extract and concentrate information from the task, content-strategic SST are hints to give ideas on how to solve the task, content-related SST are more clear and explicit hints on how to solve the task, and finally, the general glossary of important terms are hints to give background information about the terms, in this case *e.g.* bonding and solubility (Fach *et al.*, 2007). On the other end there were students who solved most of the problems on their own and where the interviewer only had to ask clarifying questions. The first excerpt is an example of a student in need of several hints to move forward, trying to solve the task on energy drinks (see table 1, topic: energy drinks, personal context, task on taurine's and caffeine's solubility in RedBull®) where the hints in form of MHC-C-operators are given in bold italics, and where '...' means that the student is quiet, thinking for more than 3 seconds:

- *Student: When I compare caffeine and taurine, I don't know which one is more soluble...*
- *Interviewer: Any idea where to start?*
- *S: No...*
- *I: Any important functional groups? [name]*
- *S: Taurine has an OH and an amine, and caffeine carbonyl groups... and caffeine has a cyclic structure... don't know what more to say...*
- *I: Can you **describe** how these functional groups relate to solubility?*
- *S: OH is soluble in water so... taurine must be soluble...*
- *I: Anything besides the hydroxyl group?*
- *S: It's always OH I look for...*
- *I: Why is OH important?*
- *S: Then it can be hydrogen bonding with water...*
- *I: Is it only OH that can give hydrogen bonding?*
- *S: I think so... or... no... wasn't it N, O, F or something... yes, and nitrogen, then perhaps the NH₂-group... could that be soluble? Isn't that a base?*
- *I: Could a base **explain** solubility?*
- *S: Hmm... Yes, yes of course... then it would be an ion, and even more soluble...that's right...*

To give one example of a student who solved more of the problem on herself, the following quote represents a more broad response to the question on how the medical drugs can be spread in the environment (see table 1 and figure 1) represents this:

- *S: I think about that the drugs have to be dissolved in water, then a trick we have learnt is to check the amount of OH-groups since they enhance solubility by hydrogen bonding, but it's also important which part is not soluble in water, not polar, and this part (points at the left side of Ipren), has lots of carbon and this big part will not be dissolved in water as easy as this (points at the oxygen atoms in Treo), and I think it's less polar, but I don't know what happens with this part, the amid or amine or whatever it is, but I think I would go with this who has an OH-group, I mean all has one OH-group but this is smaller, less polar...*
- *I: Do you consider other parts than the OH-group?*
- *S: Perhaps this nitrogen, I really don't know, but if it's something, it must be the N since that's the only thing that's not just carbon and hydrogen, but I'm not sure what it will do, the nitrogen is bonded to a*

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3 *hydrogen, is this important? It might be something like acids and bases, like NH₃, being a base, would this*
4 *make it easier to spread the drug into the environment? I'm not sure here...*
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6 This student exemplifies how the medical drugs are dissolved in the environment by discussing
7 water-solubility and polarity as well as size and she discusses these parts without the need of any
8 hints from the interviewer to move forward, only one clarifying question. By applying Taber and
9 Watts' (2000) key parameters, this response has the structure of an explanation, is logically
10 consistent and is correct regarding content.
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12 13 14 **Analysis**

15 To scrutinize students' application of chemistry content knowledge, the transcripts from the
16 interviews were analysed using an iterative process by reading the transcripts several times, and
17 thereafter, coding segments were identified. During the coding process, annotated descriptive
18 and interpretive comments were made in the margins of the transcripts. The inductively derived
19 categories that emerged became coding categories by using the content areas from the syllabus
20 (Swedish National Agency for Education, 2000) and their concepts found in the students'
21 chemistry textbooks (Andersson *et al.*, 2008; Henriksson, 2007). Content areas were for example
22 'chemical bonding', 'structure of matter' and 'organic chemistry', and their concepts were for
23 instance solubility, polarity, size, electronegativity and different kinds of bonding, see table 2 in
24 the result section. By using the quote above as an example, the second students' first utterance
25 was first coded into the following concepts: solubility (from the student mentioning *dissolved,*
26 *solubility, soluble*), functional groups/organic classes (*OH, carbon, amid, amine*), size (*big part, smaller*),
27 polarity (*not polar, less polar*) and chemical bonding (*hydrogen bonding*). These concepts were
28 thereafter categorized into the content areas presented in the result section. As a result of every
29 student solving two tasks each, there were 40 student responses, eight for every topic. The coding
30 and categorizing was made by the first author twice, with three months in-between, using an
31 Excel spread sheet where every utterance from both the student and interviewer were coded both
32 by content and by complexity level. The second author coded parts of the material (8 task
33 solutions with 85 statements out of the 40 solutions) and since inter-rater reliability was high
34 (Cohen's kappa $\kappa=0.906$) and differences were easily negotiated, first author's coding was
35 decided to be sufficient.
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46 **Results and Discussion**

47 To get background information foregrounding the research questions given in this paper, it was
48 important to investigate how familiar the students were with problems like these. Previous
49 research often have had the design where conclusions are drawn about students' learning
50 outcomes by investigating CBL approaches where the examination tasks still are more
51 conventional (Bennett *et al.*, 2007), however here we study students' responses to less pre-
52 structured and more complex chemistry problems without knowing more about their teaching
53 than looking at their textbook and their ordinary examination test, in other words, the other way
54 around compared to most previous studies. When asked to compare these context-based
55 problems with chemistry tasks the students usually meet in school, students claimed that these
56 problems were unfamiliar. The students were more used to straightforward algebraic tasks in
57 their textbooks, *i.e.* exercises. When investigating the students' chemistry textbooks (Andersson *et*
58 *al.*, 2008; Henriksson, 2007), it is evident that these textbooks mainly present exercises asking for
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3 lower order thinking like recall of memorized facts or solving repetitive algebraic tasks (Bergqvist
4 *et al.*, 2013). However, in examination tests, sometimes there are a few problems where there is
5 more background information given, presented in this exemplary quote: *The tasks I meet in*
6 *chemistry are not like this, in the textbook the tasks are mostly shorter with a clear, simple question. I just give the*
7 *correct answer. In a test, there are sometimes one or two tasks with more text, and where I have to write more. But*
8 *still, I often know what the teacher wants.* All three teachers who had students participating in this
9 study shared their examination tests in organic chemistry making it possible to validate the
10 students' opinion that the context-based problems from this study are perceived as new and
11 unfamiliar to the students. The utterance from the quote shown above that you "just have to give
12 the correct answer" relates clearly to the rote learning emphasis common in school. Moreover,
13 the focus on "what the teacher wants" was a very common comment; almost all students related
14 their responses to what they thought their teacher was looking for. This might just be a way of
15 wording, however, the idea that students learn to solve problems in a way to please their teachers
16 is something to consider, what purpose do the students have for their own learning?
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23 **Students' application of chemistry content**

24 To answer the first research question on how students apply their chemistry content knowledge
25 when solving the context-based problems, it was important to emphasise the chemistry focus in
26 the tasks. As a consequence, all tasks had a focus on combining the content areas 'organic
27 chemistry' with 'chemical bonding'; and all contained structural formula, at least as a hint, as a
28 way to make the students aware of the problem being a chemistry task. After analysis of the
29 content knowledge the students applied when solving the tasks, it was apparent that the students
30 recognized the connection between organic chemistry and chemical bonding. It was obvious in
31 all students' responses that problems on organic chemistry, especially with the structural formula,
32 made them look for functional groups, for instance exemplified by the following quote: *When I get*
33 *structural formula, I always try to find functional groups. If I find OH, then it's soluble in water.* However, the
34 student is quite brief in her utterance and the approach to remember factual knowledge is
35 evident, by stating that hydroxyl groups make something soluble in water. The structural formula
36 in the task was a way to ensure that students gave responses using chemistry content knowledge,
37 a clear strategy students had when solving a context-based problem in the pilot study
38 (Parchmann *et al.*, submitted).
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45 Some chemistry concepts were common for students to apply, for instance solubility,
46 polarity, and the molecules' size. For an overview of the most common content areas and
47 concepts used to solve the context-based problems, see table 2. Many tasks concentrate on
48 solubility and therefore the concept of polarity is given as an explanation for solubility in almost
49 all responses. However, it was a Swedish expression called "lika-löser-lika" (translated into
50 English to "like-dissolve-like") that the students mentioned repeatedly. In Sweden, students meet
51 this expression early in their science schooling, in middle school or at least in lower secondary,
52 and this expression is given by almost all students in their responses, for instance in the quote: *If*
53 *this drug is supposed to be dissolved in the blood, it has to look like blood since it's "lika-löser-lika", it's always*
54 *that in chemistry.* When asked to elaborate and explain this expression, one student exemplifies
55 water-solubility with an example: *Water is H-O-H and to find something that is alike, it's always OH-*
56 *groups I look for, since the only difference is a hydrogen atom. So if I find OH-groups in a molecule, then it's*
57 *soluble in water since they look alike.* This clear connection between hydroxyl groups and water-
58 solubility was seen in all students' responses. By giving the students a structural formula, they
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emphasised entirely on hydroxyl groups: *I just look for OH, if I find that, then it's polar. If I just find carbon, then it's unpolar. It's as simple as that.* These quotes show a clear connection to recall of factual knowledge and the idea that chemistry problems always have 'one correct answer'.

Table 2. Common concepts used in students' responses to the different problems.

Content area	Examples of concepts	Topics & Contexts
Structure of matter	Atomic and molecular structure, molecular size	All topics with their contexts
Chemical bonding	Electronegativity, polarity, solubility, "lika-löser-lika"	All topics with their contexts
Organic chemistry	Classes (e.g. alcohols, carboxylic acids), functional groups	All topics with their contexts
Acids & bases	pH, acids, bases	Medical drugs, Energy drinks, Soaps & detergents with their contexts
Energy & enthalpy	Combustion, bond energies	Fuels with its contexts

Besides chemical bonding and polarity, some students mentioned 'acids & bases' as an explanation for solubility. This content area was also given as an explanation from the chemistry professor as a possible solution to some of the tasks, for instance to explain how the medical drugs or the molecules in energy drinks are dissolved in the body or the environment. Taurine, one of the ingredients in energy drinks, is a zwitterion, in other words, an overall neutral molecule with both a negative and positive charge, like amino acids. Upper secondary students have not met the term zwitterion in the textbooks and probably not from the teacher. However, some students discussed possibilities for parts of molecules being acids and bases respectively. The connection with acids was molecules containing carboxylic groups (*i.e.* -COOH) or even sometimes isolated hydroxyl groups (*i.e.* -OH) where a hydrogen ion was suggested by some students to leave the molecule. Molecules were suggested being bases if they had an amino group (*i.e.* -NH₂), one example already given above when a student explained how taurine could be dissolved in water. The possibility for amino groups to take part in hydrogen bonds was never suggested; hydrogen bonds were only emerged with hydroxyl groups, a result also found in the pilot study (Parchmann *et al.*, submitted).

Furthermore, the topic-related aspects of the tasks were often mentioned in the students' responses. The topic of 'soaps & detergents' is mentioned by all students, often in relation to what they have discussed at chemistry lessons or read in the chemistry textbooks. When describing fatty acids, the picture of a molecule with a polar head and an unpolar tail was frequently given, for instance in the following quote: *We have talked a lot in chemistry class about fatty acids and their polar head and unpolar tail, like hydrophilic and hydrophobic parts, for instance when discussing fats and soaps.* The function of soaps and detergents, fuels and fats are presented in all textbooks used by the students, thereby previously potentially known to the students. The topic of energy drinks is not presented in the textbooks; still this topic is mentioned in the responses, mainly by claiming the task to be both interesting and relevant. This relevance of an authentic topic can be exemplified by: *Both me and my friends drink a lot of Monster and it's good to see the molecules to understand how it works in the body, I haven't really thought about that before. Now this taurine-molecule makes me curious...* It was apparent that the topics encouraged the students to solve the problems and to not

only give one short answer. To summarize how the students applied their content knowledge when solving these context-based chemistry problems, the combining of two content areas, *i.e.* organic chemistry and chemical bonding, was apparent in all students' answers, however mostly by recall of memorized facts. The most common concepts used to combine these areas were solubility and polarity, making these concepts threshold concepts important to master for further understanding of these problems.

Misconceptions of chemistry content

For the second research question, students' misconceptions were scrutinised. The relationship between chemical bonding and the 'octet rule' highlighted in previous research (Levy Nahum *et al.*, 2010), and the anthropomorphic explanations (Adbo & Taber, 2013) became apparent here as well. One exemplary quote illustrates this: *When I saw S and double bonds in taurine, that made me worried... But in caffeine, there are lots of carbons, that's not soluble in water... I would like to say that taurine is most soluble, it has OH, but the S makes me confused... How can it be two double bonds to the sulphur, and more than four bonds in total? Don't atoms want four bonds? And isn't sulphur bad? I think it's bad for the environment, like in fuels, we don't want to have sulphur compounds.* Several students reacted on the sulphur atom; some even questioned if the structural formula was drawn correctly. The anthropomorphic explanations that atoms 'want' four bonds were found in several different responses, not only in the task on energy drinks.

When students were asked to elaborate their responses on polarity, it was evident that several students have memorized electronegativity values in a way thinking about the atoms themselves as positive or negative without considering the bonding to other atoms. Taagepera and Noori (2000) have found this misconception among university chemistry students, claiming the urge to teach chemical bonding in another way, by asking the 'why?' question, not only remembering factual knowledge of Pauling electronegativity numbers. Polarity explains the dislocation of electrons in a covalent bond where one atom can attract the electron pair more than the other. However, it is always elementary to take into account both atoms in a bond, for instance in a bond between a carbon atom and a hydrogen atom, the shared electron pair is relatively equally shared since carbon and hydrogen has almost the same electronegativity value, the bond is therefore unpolar. On the other hand, the bond between a hydrogen and an oxygen atom has a dislocation of the electrons towards the oxygen atom because it attracts the electrons more, this bond is therefore polar. This dislocation of electrons is in chemistry represented using the sign of δ^+ and δ^- . To exemplify this misconception, the following quote is given:

- S: *Since the medical drug has to be dissolved in water, it has to be polar since water is polar and "lika-löser-lika"...*
- I: *How do you know if a molecule is polar?*
- S: *That's something I remember from last year, when we read about chemical bonding, I know oxygen is negative and hydrogen positive, so I remember that water is polar, we always wrote δ^+ and δ^- ...*
- I: *This was regarding water, how about the medical drug molecules?*
- S: *They are more tricky since they are bigger, but I would look for C and O, lots of C then unpolar, lots of O then polar...*
- I: *So you count the number of O to decide if the molecule is polar?*
- S: *Yes, they are δ^- ...*
- I: *Always?*
- S: *Yes... aren't they?*

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In the 15 tasks, almost all students mentioned the content area ‘structure of matter’. Concerning size, the common idea was that small molecules are more soluble in water, because, as one student claimed: *the water molecule is so small and has to get close to the molecule it’s supposed to dissolve, therefore it’s better if the molecule is small.* When the task concerned molecules with carbon chains, for instance fatty acids or fuels, the length of the carbon chain was central, mainly to interpret the strength of intermolecular bonding like van der Waals forces. One important translation experience was noticed here since previous research has highlighted difficulties when intermolecular bonds sometimes are named ‘forces’ (Levy Nahum *et al.*, 2010). In the textbooks these students met, both intra- and intermolecular bonding are in Swedish named ‘bonds’. However, both this study and previous Swedish studies (Adbo & Taber, 2014) still emphasise students’ misconceptions about bonding types. One exemplary quote discussing fatty acids in fats (see table 1) describes this confusion: *Well, yes, when it’s double bonds in the tail, then the bonds between the molecules will be stronger. When there are only single bonds in the tail, there will only be weak van der Waals, the tail will not stick together that much. But if it has a double bond the bond between the tails is stronger.* Here the student mixes ideas about strength of intra-molecular bonds, *i.e.* that double bonds are stronger than single bonds, with the strength of intermolecular bonds, *i.e.* van der Waals forces.

The discussion about single and double bonds in fatty acids, *i.e.* saturated and unsaturated molecules, was always on a rote level. Students recalled memorized facts, that double bonds in carbon chains gave a cis and trans structure, one being straight, the other bent. One student started her response to the question in the task on chemical properties of fatty acids: *I really don’t know what chemical properties are... perhaps solubility... or how they react. Then I know that unsaturated fatty acids are bent, if there’s a double bond... you know... our teacher talked a lot about cis and trans... We have learnt that it’s bad with saturated fatty acids because they are straight and then they can go into the cells... that’s not good...* It was common to give reference to what the teacher had said, and also to claim they ‘learn’ and ‘remember’ things. One final quote on structure emphasises this rote memorization regarding structure:

- I: *You mentioned cis and trans in the beginning, could you enhance you answer?*
- S: *Yes, cis is straight, trans is bent.*
- I: *What does that really mean, can you say anything more?*
- S: *Well, it’s the carbon chain I look at, and if it’s straight then it’s cis, it’s on the same side...*
- I: *What is on the same side?*
- S: *... Hmm... It was something about different or same groups on the same side of the double bond... but I really don’t remember...*
- I: *You say double bond...*
- S: *Yes, it has to be a double bond to be cis and trans, this I remember...*
- I: *Why?*
- S: *I don’t really know, I don’t remember...*

In summary, misconceptions have been found in some of the students’ responses, often related to the two most common applied concepts, *i.e.* solubility and polarity. These misconceptions have been evident in previous research, therefore we emphasise the need to improve students’ understanding of these threshold concepts.

Problem-solving approaches with regard to the contextualization of the tasks

To answer the final research question, the contextualization of the content was focused. The students claimed that both the five topics as well as the three contexts were interesting and

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3 relevant, especially the personal context was appreciated; hence the contextualization is found
4 important regarding the affective parts of learning. However, we were also interested in
5 investigating how students might be guided by the contextualization of the problem in two ways;
6 they could be distracted or supported by context-related information. As mentioned earlier, after
7 five interviews there was a slight change in methodology where the students met the tasks
8 without the structural formula in the beginning, since the structural formula made them look for
9 functional groups and directly discuss factual content knowledge relating to organic chemistry.
10 When saving the structural formula until later in the interview, as a hint, students often came up
11 with more broad explanations in the beginning to the topic and context, not only looking for
12 organic chemistry functional groups. This can be highlighted by an excerpt where a student
13 discusses taurine and caffeine in the energy drink RedBull® (the task mentioned earlier, see table
14 1): *I don't know what caffeine and taurine looks like, but if they are soluble in water, and they must be since we*
15 *drink RedBull, they have to be polar, so probably OH-groups... and I would think they are quite small, if they*
16 *were big, the small water molecule couldn't attach... it could also be an ionic compound, free ions are water-*
17 *soluble... or it could be an acid or a base depending on pH...* This broad answer could also be seen as a
18 way for the students to “be safe” and give as many different responses as possible. However, this
19 was one benefit of this change in method, that some of the students started to think in a more
20 open and broad way suggesting different content areas explaining a chemistry problem.
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27 When scrutinising how the students used the contextualised parts in the problems, it was
28 obvious that students mentioned the words used in the task. By relating to the topic of medical
29 drugs, where the three tasks are presented in figure 1, the students who chose to solve the
30 personal context mentioned the medical drugs in the body, for instance by discussing blood pH,
31 brain and digestion in the stomach; whereas the students solving the societal context discussed
32 how the molecules are spread in the environment by mentioning sewage plant, filters and
33 biological cleaning with bacteria. Examples of these connections to the context are the two
34 following quotes, one student solving the personal context and the second student solving the
35 societal context from the topic of medical drugs (see figure 1): *The medical drugs have to dissolve in*
36 *water and to get into the blood. But it's also important that the molecule can be digested in the stomach, it has to*
37 *be absorbed, and then it cannot be too big to get out from the stomach to the blood system...* and for the societal
38 context: *They [the medical drugs] must pass the sewage plant, without being destroyed, I mean, they have*
39 *biological cleaning with bacteria and then the medical drugs cannot change, and they must have long half-life, and*
40 *be soluble in water...* The first student discusses blood and stomach whereas the second student
41 mentions sewage plants and biological cleaning using bacteria, thereby exemplifying the actual
42 use of the contextualization of the task.
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49 To quantify how common it was to use the contextualization of the task in the responses,
50 table 3 presents the number of students who discussed the context in their answers one or
51 several times. It is apparent that the personal context, which was most common for students to
52 choose when deciding which task they wanted to solve, had a clear impact on students'
53 responses. The use of the topics was also evident, students related their responses to the topics
54 with one exception, when solving the problem on fuels, and only half of the students highlighted
55 the connection to the topic. This use of context-related information was more common after the
56 change of method, inclining the advantage of saving the structural formula as a hint in the
57 process. We therefore argue that the context of the problems actually influences students'
58 responses, for instance by giving them new ideas on how to solve the problem and not only
59 focus on the structural formula and recall of factual knowledge of functional groups. In
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summary, even though students are not familiar with problems requiring higher order thinking, we argue for the use of these in school chemistry, both as problems to learn from as well as assessment tasks. Still, we need to get more insight on *how* students make use of this contextualization in the problem-solving process, which will be the focus of our forthcoming paper.

Table 3. The use of contextualization in students' responses to the context-based chemistry problems.

Topic	Context	Number of responses	Contextual terms mentioned in the response
Medical drugs	Personal	5	5
	Societal	2	1
	Professional	1	0
Energy drinks	Personal	6	6
	Societal	0	n/a
	Professional	2	0
Fats	Personal	6	5
	Societal	1	0
	Professional	1	0
Fuels	Personal	6	3
	Societal	1	1
	Professional	1	0
Soaps & detergents	Personal	7	7
	Societal	1	1
	Professional	0	n/a

Conclusions and Implication

Students' applications of chemistry content when solving context-based problems has been scrutinised to get an in-depth insight on students' explanations when they are given problems where there is not only one single correct answer. The problems in themselves demand complex higher order thinking, something the students need to practice since they are unfamiliar with this from their previous school chemistry. CBL approaches have sometimes been criticized to highlight too much the affective parts of learning (*e.g.* Marks & Eilks, 2010; Sevia & Talanquer, 2014), to exclusively make students interested and motivated to study science. Smith (2011) even expresses "considerable suspicion" within a group of professional chemists concerning CBL approaches because of future students' probable lack of factual knowledge. By relating to Roberts' (2007) dichotomy of scientific literacy, this orientation towards Vision II, that science primarily is related to real-life situations, and not on Vision I, with the orientation towards the science subject matter, has been an important starting point for this study where the chemistry content areas with their concepts have been analysed, both regarding the design of the problems in themselves as well as students' responses to the tasks. Although we find it important with Vision II, there has perhaps been too much concentration on the everyday life making the content knowledge invisible, as claimed by Sevia and Talanquer (2014). At upper secondary level, preparing for university chemistry, the subject matter has to be emphasised, however we

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3 think it is possible to do so within the CBL approaches and by applying both Vision I and II, for
4 example by using well-designed context-based chemistry problems for students to solve.

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6 When designing these problems, the awareness of the topics, contexts and content areas
7 with specific concepts have been time-consuming, however the design principles have been
8 helpful to both assess students' application of content knowledge as well as emphasising
9 authentic and relevant topics to engage students in the problem-solving process. Our tasks are
10 short enough to solve within existing chemistry courses and thereby possible to use in school
11 chemistry even though the curriculum has no explicit context-based focus. Several previous
12 research projects are more extensive and are carried out in countries with full curricula changes;
13 tasks like those investigated here can be implemented as starting points of a CBL approach.
14 Based on the results we found we claim that those tasks would engage students to look for
15 connections between the chemical content they have learned (or should learn) and phenomena or
16 questions they meet in their daily-life. Students' apparent use of the contextualization of our
17 tasks, especially regarding the personal context has been supporting and not distracting to the
18 students. This assures that the context in itself is helpful when solving the problem, not being
19 merely a decoration or a motivational trick something Nentwig *et al.* (2007) warn about.
20 Therefore, we assert the possibility to use these tasks to work on as learning situations, not only
21 as assessment tasks, for students to develop their problem-solving skills and improve their
22 explanations to be more effective and structured. Still, they are suitable to assess students'
23 content knowledge since they ask for broad answers highlighting for students that chemistry
24 problems have more than one single correct answer students are meant to memorize and
25 thereafter recall. Thus we claim that implementation of these kinds of problems when teaching
26 chemistry is a viable route to enhance higher order thinking in chemistry classrooms. One
27 evident example of higher order thinking from this study is represented by students' own
28 question-posing; when the students were encouraged to develop their responses, the students
29 often responded with questions and talked in a dialogic way to move further in their problem
30 solving. It was also apparent that these tasks made the students reason further and develop their
31 responses, not only stating the 'correct answer'.
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35 Regarding the chemistry content areas, chemical bonding has been found to be a
36 fundamental area important to master to give explanation to these problems. Almost all
37 responses given by our students can be related to chemical bonding, when discussing solubility,
38 chemical reactions or molecular structure. However, since students' misconceptions within this
39 area are common for instance with the central concept of electronegativity, we concur with Levy
40 Nahum *et al.*'s (2007; 2008; 2010) request for a new bottom-up approach where chemical
41 bonding are taught based on physical elemental principles by applying the idea of continuum of
42 bond strengths and by avoiding the dichotomous classification of bonds as covalent/ionic and
43 intra/intermolecular. In Swedish textbooks, this new bottom-up approach has not been
44 established, and therefore we emphasise the conclusions given by Bergqvist *et al.* (2013) asserting
45 the need to fill the gap between research and textbook writers. Furthermore, since students made
46 use of the contextualization of the tasks by relating their responses to both the topic and the
47 context, we encourage teachers and textbook writers to connect their chemistry content to
48 everyday life by developing and designing problems with explicit and relevant topics and
49 contexts. Unquestionably, since students are unfamiliar with these kinds of problems, both the
50 design process of the tasks and the problem-solving process need to be implemented in both pre-
51 service and in-service training of chemistry teachers to make teachers confident to change focus
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3 from recall of factual knowledge to higher order thinking. Therefore, we would like to close this
4 paper using Henderleiter *et al.*'s words: "if the goals of chemistry instruction included fostering
5 critical thinking skills and equipping students with the skills and strategies needed to solve
6 problems in contexts beyond those they were taught, then instructional practice must model and
7 apply what is known about how people learn." (Henderleiter *et al.*, 2001, p. 1129). This was stated
8 several years ago, however, still a valid statement worth to highlight.
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