Stockholm University

Chemistry education for citizenship

Didactic modelling for complexity in students' discussions

Cecilia Dudas

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Till Benjamin & Josef

Abstract

One of the challenges upper-secondary school chemistry is dealing with, is how to contribute to both the development of scientific knowledge and students' opportunities to develop democratic citizenship. This thesis aims to explore how science education for citizenship and Bildung can develop in different chemistry education contexts. Research shows that chemistry education is struggling with its relevance in relation to students' out-of-school experiences. The thesis also aims to analyse whether activities which enable students to unfold the inherent complexity in chemistry might be one viable approach towards some of the challenges chemistry education faces. This thesis is based on two studies which are described in two papers. These studies were conducted as in-situ studies at two upper-secondary schools in Stockholm. Students' discussions were recorded on video and transcribed. The discussions were analysed using Practical Epistemological Analysis (PEA) and Deliberative Educational Questions (DEQ).

The first study was conducted with a design based approach in two cycles. A didactic model for complexity in students' discussions regarding sustainability issues was simultaneously developed. The didactic model was extracted through an analysis of the considerations emerging from the students' discussions. Four different kinds of considerations emerged: *factual considerations with sufficient facts, factual considerations with insufficient facts, value-based considerations with sufficient facts, and value-based considerations with insufficient facts*. Design principles for educational activities that aim to support students in the visualisation of complexity in sustainability issues were also developed.

The second study was conducted in a context that focussed on the chemistry content (i.e., metabolism in the human body) rather than environmental or societal perspectives. In this context, two kinds of considerations emerged: *factual and exploratory considerations*. The analysis showed that these only partly overlapped with the previous categories. Hence, the didactic model for complexity was refined in the new context. The study shows the importance of enabling students to experience chemistry as tentative, as this can contribute to increased student participation.

One conclusion is that while factual considerations are an important element of chemistry education, students also need to encounter other kinds of considerations. The results indicate that different kinds of considerations are needed to facilitate complexity in students' discussions. One implication for education is that chemistry education needs to include activities that enable students to encounter uncertainty, as uncertainty and unpredictability seem to facilitate different kinds of considerations, and thereby complexity. The importance of introducing uncertainty into chemistry education is underlined by the didactic models. I argue that the models can be a valuable contribution to teachers' reasoning and decision-making in the design and analysis of activities in chemistry education.

Keywords: Chemistry education, Upper-secondary education, Science education for citizenship, Bildung, Didactic modelling

Sammanfattning

En av de utmaningar som kemiundervisning på gymnasiet står inför är hur undervisningen kan bidra till att både bidra till kunskaper i kemi, och samtidigt bidra till elevernas möjligheter till att utvecklas som demokratiska medborgare. Ett övergripande syfte för denna avhandling är därför att undersöka hur naturvetenskaplig medborgarbildning kan utvecklas i olika kontexter inom kemiämnet. Tidigare forskning visar att kemiundervisningen inte upplevs som relevant i relation till elevernas liv utanför skolan. Avhandlingen syftar därför också till att analysera huruvida undervisning som ger elever möjlighet att uppmärksamma och utveckla den komplexitet som föreligger i kemiämnet kan vara ett sätt att bemöta de utmaningar som kemiämnet står inför. Avhandlingen är baserad på två studier som beskrivs i två artiklar. Dessa studier genomfördes som in-situ studier på två gymnasieskolor i Stockholm. Det empiriska underlaget utgörs av elevers diskussioner som spelades in med video och transkriberades. Diskussionerna analyserades med Practical Epistemological Analysis (PEA) och Deliberative Educational Questions (DEQ).

Den första studien genomfördes som en designbaserad studie i två cykler. Parallellt genomfördes en didaktisk modellering. Genom den didaktiska modelleringen extraherades en didaktisk modell för komplexitet i elevers diskussioner rörande hållbarhetsfrågor. Modellen utvecklades utifrån fyra olika typer av överväganden som identifierades i elevernas samtal: *faktamässiga överväganden med tillräcklig faktakunskap, faktamässiga överväganden med otillräcklig faktakunskap, värdemässiga överväganden med tillräcklig faktakunskap och värdemässiga överväganden med otillräcklig faktakunskap*. Genom studien utvecklades också design principer för undervisning som syftar till att stötta elever att uppmärksamma den komplexitet som föreligger i hållbarhetsfrågor.

Den andra studien genomfördes i en kontext som fokuserar kemiinnehållet (i föreliggande studie metabolismen) snarare än miljö-eller samhällsperspektiv. I denna kontext utkristalliserades två olika typer av överväganden: *faktamässiga och explorativa överväganden*. Analysen visade att dessa bara delvis överlappade med de kategorier som utkristalliserades i den tidigare studien. Modellen förfinades således i den nya kontexten till att bestå av faktamässiga och explorativa överväganden. Studien visade också på vikten av att låta eleverna erfara kemi som tentativt, då detta verkar möjliggöra ökat elevdeltagande.

En slutsats är att faktamässiga överväganden är en viktig del av kemiundervisningen, men att elever också måste få möta andra sorters överväganden för att undervisningen ska kunna bidra till medborgarbildning. Olika typer av överväganden är också viktigt för att stötta eleverna i att uppmärksamma och utveckla komplexitet. En implikation är att kemiundervisning behöver innehålla aktiviteter som erbjuder elever att möta osäkerhet, då osäkerhet och oförutsägbarhet verkar möjliggöra olika typer av överväganden. Betydelsen av att inkludera osäkerhet i kemiundervisningen synliggörs också i de didaktiska modellerna. Dessa kan därmed vara ett värdefullt stöd för lärare i resonemang och beslutsfattande rörande design och analys av undervisning som syftar till att stötta elever att utveckla komplexitet i sina/deras samtal.

Nyckelord: Kemiundervisning, Gymnasieskolan, Naturvetenskaplig medborgarbildning, Bildung, Didaktisk modellering

List of Papers

I Dudas, C., Rundgren, C.-J., & Lundegård, I. (2018). Didactic modelling of complex sustainability issues in chemistry education. *Nordic Studies in Science Education (NorDiNa), 14*(3), 267-284.

II Dudas, C., Rundgren, C.-J., & Lundegård, I. (Submitted). Exploratory considerations in chemistry education—didactic modelling for complexity in students' discussions.

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Stockholm, september 2019
Cecilia Dudas

Contents

Introduction

> Mark: It's been such a long time since the results were this uncertain, that I had to look for them like this.
> Zoe: But it was also a long time ago we analysed like this in a school project; this was more fun than other things.

This conversation between two students is from one of the studies undertaken as part of this thesis. It illustrates how uncertainty introduces a challenge and a need for analysis—and this made the activity fun!

As an upper-secondary chemistry teacher, I have always striven to make the content and methods used in chemistry education relevant for my students. One aspect of this is the inclusion of activities that help students develop useful knowledge for real-life contexts. Research shows how chemistry education has been struggling with its relevance, and an abundance of studies in science education describe a declining interest in chemistry education among up-per-secondary school students. Several reasons for this have been outlined, e.g., lack of relevance for students and their communities, and pedagogical methods that make it hard for students to connect the content to their everyday lives (e.g., Aikenhead, 2006; Eilks & Hofstein, 2015). Previous research also shows that the pedagogical methods of chemistry education have often presented a stereotypical image of chemistry as uniform and absolute. Traditionally, there have been limited opportunities for students to contribute their own ideas and experiences in chemistry education (Basu & Calabrese Barton, 2010).

As a teacher, I have experienced how activities I anticipated would enable students to develop complexity in their discussions only delivered very simple and basic discussions or arguments. This was, for instance, the case in the first cycle in the first study of this thesis. Other activities facilitated a significant degree of complexity in the students' discussions. When I was unable to discern what made the activities contribute to different levels of complexity I became interested in analysing how and when complexity unfolds in students' discussions.

For me as a teacher, the greatest didactical challenges are about how to increase student participation in relation to traditional chemistry content. However, I realised that most of the previous research dealing with student participation, complexity and education for citizenship has been conducted in socio scientific or environmental contexts. As a large part of the upper-secondary chemistry curriculum involves traditional fact-based content, it became important for me to locate my second study in a chemistry content context.

Four years ago, I got the opportunity to participate in the Graduate School for Didactic Modelling and Analysis for Science Teachers (NaNo). This provided me with opportunities to systematically analyse some of challenges I outlined above. Therefore, this thesis revolves around science education for citizenship, as well as student participation and complexity in both environmental and chemistry content issues. As a researcher, I aimed to develop tools which could be useful to me and other teachers in our everyday practice. However, this thesis does not aim to deliver comprehensive design principles, models or activities for chemistry education. Rather, I hope to introduce some ideas that might inspire teachers to further develop their own teaching. This thesis also aims to contribute theoretically to science education research about didactic modelling and complexity in students' discussions.

Aim and research questions

One of the challenges upper-secondary school chemistry is dealing with, is how to contribute both to the development of scientific knowledge, and to giving students opportunities to develop democratic citizenship. The overarching objective of this thesis is to explore how science education for citizenship and Bildung can develop in different contexts in chemistry education. Research shows that chemistry education is struggling with its relevance in relation to students' real-life experiences. As there seems to be a lack of research regarding how to make the changes needed to increase the relevance of chemistry education, this thesis aims to explore how learning activities which address these challenges can be designed. Therefore, this thesis analyse whether activities which enable students to unfold the inherent complexity in chemistry, might be one viable approach.

The purpose of study one (paper I) is to develop a didactic model which aims to analyse complexity in students' deliberations about sustainability issues in chemistry education. Furthermore, the study aims to explore how education can be designed to support the students to make the inherent complexity in sustainability issues visible and how this can facilitate science education for citizenship and Bildung. Research questions for study one:

- What considerations can be discerned in students' discussions about sustainability issues in chemistry education?
- How can a didactic model that aims to analyse complexity in students' deliberations be developed from these considerations?
- How can chemistry education be designed so that it enables students to make complexity visible in sustainability issues?

An overarching objective of study two (paper II) is to explore how chemistry education can contribute to science education for citizenship. Additionally, this study aims to analyse how complexity evolves in students' discussions, and how this complexity relates to the exploratory nature of chemistry. Drawing on our previous model for complexity in students' deliberations, this study also aims to analyse how the model can be further developed in a new context. Research questions for study two:

- What kinds of considerations can be discerned in the students' discussions?
- How will the didactic model for complexity in students' discussions evolve from a chemistry content issue?
- In what ways can activities be designed to enable students to experience chemistry as exploratory?

Previous research

Science education for citizenship

Science education for citizenship is a broad concept; its general aim is to prepare students for present and future challenges. This includes participation in public debates with conflicting perspectives and values where scientific knowledge is needed to make well-informed decisions. Bildung highlights the importance not only of being able to make well-informed decisions, but also to contribute to positive changes in society. Therefore, education needs to contribute to developing critical and action competent citizens.

Scientific literacy

One fundamental question for science education is why students should study and learn science at all. Is science education for all students or merely for those who are interested in pursuing a career in science? One tradition that discusses this matter is *scientific literacy* (SL). According to Roberts (2007), while there is no consensus on the definition of scientific literacy, scientific literacy is a concept used to 'express what should constitute the science education of all students…' (Roberts, 2007, p. 729). The notion of literacy in this context can be understood as *thorough knowledgeability* (Roberts, 2007). According to Wickman, Liberg and Östman (2012) science has become something that everybody needs to know to make well-informed decisions: 'the objective of science education is learning from science, i.e. how science can be of use to students in their private life as well as citizens, regardless of whether they are going to pursue careers in science or not' (p. 40). Scientific literacy has also been defined as 'the understanding and skills that empower individuals to make personal decisions and appropriately participate in the formulation of public policies that impact their lives' (Hofstein, Eilks & Bybee, 2010, p. 1462). Furthermore, Roberts (2007) states that 'everybody agrees that students can't be scientifically literate if they don't know any science subject matter' (Roberts, 2007, p. 735).

Roberts (2007) argues that there is, and has always been, a tension within science education, with two conflicting curriculum perspectives. On the one hand, the science subject matter itself and on the other hand, contexts where science can be, together with other sources, a part of understanding and dealing with issues around us in society. Roberts (2007) calls these two perspectives Vision I and Vision II and writes: 'Vision I gives meaning to SL by looking inward at the canon of orthodox natural science, that is, the products and processes of science itself' (p. 730). The focus of Vision I is to know scientific concepts and theories, and to be able to con-duct controlled laboratory work. It is assumed that if the student learns the correct explanations for different scientific processes, (s)he can transfer this objective knowledge to other situations where it is needed, e.g., to make decisions in everyday situations (Wickman et al., 2012). Wickman et al. (2012) relate Vision I to the concept of 'induction into science' (p. 40) and argue that within the Vision I perspective, normativity (e.g., values, interests, power), is regarded as being irrelevant and could be reduced through scientific knowledge and reasoning. On the contrary, 'Vision II derives its meaning from the character of situations with a scientific component, situations that students are likely to encounter as citizens' (Roberts, 2007, p. 730). From a Vision II perspective science should be learnt as part of various contexts regarding everyday problems. Wickman et al. (2012) relate scientific literacy to 'learning from science'

(p. 40) and argue that 'Vision II can be said to transcend science and to start from questions that are already around us in society and which need to be solved by invoking science as one among other re-sources' (Wickman et al., 2012, p. 41). Normativity is thereby seen as unavoidable, and as something that can and should be an integrated part of science education.

According to Brickhouse (2011) a curricular change towards Vision II is a promising start. It will, however, not be enough if the preconceptions about what science is and how it should be taught not are changed. Furthermore, education from a Vision II perspective is probably not enough on its own to increase students' interest, since there are many other factors in students' everyday lives which are more influential when it comes to interest and choices about future careers. Related to this is also the question: 'How and where do we allow scientific literacy to emerge?' (Roth & Barton, 2004, p. 3). Traditionally, this has been answered by exposing the students to a fake image of a scientists' science, i.e., a science which claims to be pure and untainted by values and other connections to everyday life (Roth & Barton, 2004). Researchers often turn to scholars in science studies, e.g., Latour (1999) or Knorr Cetina (1999), to learn what scientists do. Based on this knowledge, educators have been trying to design education to teach students the same competences as the scientists have (Brickhouse, 2007). These competences might be useful from some perspectives of scientific literacy, but Brickhouse argues that scientists are not making more thoughtful personal choices or becoming better citizens than the rest of the population, and asks: 'If scientists are a bad model for scientific literacy, where can we find good models?' (Brickhouse, 2007, p. 92). According to Brickhouse we should take the opposite perspective and ask: 'who are scientific literates and what do they do?' (Brickhouse, 2007, p. 90).

Roberts (2007) concludes that Vision I and Vision II advocate fundamentally different perspectives about what it means to be scientifically literate. Sjöström, Frerichs, Zuin & Eilks (2017) relate Vision I to a traditional science curriculum and Vision II to a context based science curriculum. However, there are also risks related to overemphasising either Vision I or Vision II. Therefore, according to Wickman & Ligozat (2011) '[s]cientific literacy is not primarily about knowing either scientific concepts or competent action in isolation. Instead, it is about the competent use of science in various settings in private and public life' (Wickman & Ligozat, 2011, p. 146).

Bildung

Bildung is an educational perspective that focusses on the social and cultural dimensions of education. Bildung concerns the formation of the whole person and aims to develop an individual's personality (Duit, Gropengiesser, Kattmann, Komorek, Parchmann, 2012). Bildung includes both a process and a way of being, where the process consists of both personal and societal development. Elmose & Roth (2006) argue that Bildung does not only include being able to make well-informed decisions, but also a responsibility to change society in positive ways. Bildung also involves developing an independent and critical approach to the society one lives in. This relationship between independence and responsibility creates a tension between social and personal values (Sjöström et al., 2017).

Traditionally, science education has not been regarded as relevant for the development of Bildung, since Bildung was related to the Humanities (Sjöström et al., 2017; Wickman et al., 2012). Bildung has been connected to upper-class traditions and conservative political ideas. The subjects within science have historically been more related to vocational and practical education than humanities and arts. This might be one explanation for why the focus of science education has developed towards 'induction into science' rather than 'learning from science' (Wick-man et al., 2012, p. 40). However, today the Bildung perspective is understood as an

education for all students and all subjects (Wickman, 2014). A Bildung-oriented chemistry education includes ethical and socio-cultural perspectives and aims to develop critical and action-competent citizens (Sjöström, 2013). Furthermore, a Bildung-centred chemistry education can contribute to a person's scientific (chemistry) literacy (Sjöström, 2013). While Bildung in science education is related to scientific literacy they are not synonymous, as Bildung is a broader concept (Sjöström et al., 2017; Wickman, 2014).

Education for Bildung relates to present and forthcoming challenges in society. According to Beck (1992), we live in *risk society*, meaning that we have the knowledge to develop more complex innovations in science and technology, but the consequences of the production and the use of those products might be unpredictable and uncontrollable. Innovations initially regarded as positive, have been shown to contribute to significant risks for health and environment, e.g., the combustion of fossil fuels, use of pesticides, and additives in plastic materials (Elmose & Roth, 2005). Living in risk society brings new challenges for education, especially for chemistry education and one way to address those challenges may be through a Bildung-oriented education (Burmeister, Rauch & Eilks, 2012; Elmose & Roth, 2005).

Pluralistic environmental education

One perspective that discusses education for citizenship is *Education for Sustainable Development*. However, this is a debatable area. Some critics argue that learning *for* something does not promote critical thinking, which is regarded as a core value in environmental education (Jickling, 2004; Jickling & Walz, 2008; Van Poeck & Vandenabeele, 2011). It has been suggested that that learning *from* might be a concept which better captures the essence of environmental education. To avoid this dilemma, we will use the notions *pluralistic environmental education*, and *sustainability issues* in this thesis.

A pluralistic environmental education aims to prepare students to be both willing and able to participate in present and future democratic debates. Hence, sustainability issues are closely connected to citizenship and Bildung: 'We argue that presenting sustainable development issues as 'public issues', as matters of public concern, allows educational practices to move beyond socialisation and to experiment with the tension between a sense of urgency and the need for democratic participation' (Van Poeck & Vandenabeele, 2011, p. 543). Here, education can offer an arena where one can practice one's participation in debates about environmental issues that have emergent conflicts (Sandell, Öhman & Östman, 2003). Furthermore, deliberative discussions can support students' visualisations of different perspectives and values (Lundegård & Wickman, 2007; Van Poeck & Vandenabeele, 2011). Pluralistic perspectives on education also relate to the democratic perspective *citizenship as practice* (Van Poeck & Vandenabeele, 2011). This perspective does not focus on the abilities citizens should strive for, but on citizenship as it develops in democratic participations. Within this tradition, subjectification is essential. This includes dis-identification and critical discourses to develop new ways of being (Lundegård & Wickman, 2012; Van Poeck & Vandenabeele, 2011).

In this thesis, I will use the term *pluralistic educational tradition* to describe learning activities which include students' discussions about environmental issues where they are encouraged to experience each other's different perspectives and values.

The relevance of chemistry education

Chemistry education challenges in Swedish schools have been highlighted in recent years. This thesis focuses on upper-secondary chemistry education. Science education research claims that school chemistry is often perceived to be unpopular among upper-secondary school students and that students' interest in chemistry is declining. Common explanations for this are that students do not regard chemistry as being relevant to them, to their community or their everyday

lives (Eilks & Hofstein, 2015; Hofstein, Eilks & Bybee, 2011; Hofstein, Eilks & Bybee, 2010; Holbrook, 2008; Osborne & Dillon, 2008).

Facts and knowledge in science education are often presented as objective and pure, thus providing students with a stereotypical image of science as socially sterile, authoritarian, non-humanistic and absolutely true (Aikenhead, 1996). Science is also often presented in a way that shapes the image of science as being hard to learn and only for gifted students (Kelly, 2014; Lemke, 1990; Lindahl, 2013). Neither has science education traditionally included students' questions and ideas, and the students have been limited to learning content chosen by the teacher (Basu & Calabrese Barton, 2010; Roth & Barton, 2004). This might be one explanation for why students have not considered the chemistry content as relevant or meaningful for them (Aikenhead, 2006; Hofstein et al., 2011; Lindahl, 2003). It is often argued that the science taught in schools is very different from how scientists actually practice science, with schools being accused of reproducing a mock image of scientists' work (Brickhouse, 2011).

The chemistry taught in schools is very similar to the 'university administrative unit known as department of chemistry' (Aikenhead, 2003, p. 115). Furthermore, science teachers often identify themselves as scientists rather than educators: 'One major challenge for chemistry and physics teachers is to rethink and reformulate their professional identities away from being loyal and accountable to their discipline towards another identity that celebrates views of relevance other than the "wish-they-knew science"' (Aikenhead, 2003, p. 125). However, the purposes of the chemistry subject in schools and the science of chemistry are essentially different. The aim of the school subject is often related to several sciences and should enable students to create experiences for life; and support students' decisions and actions in different contexts, both in school and in real-life situations, thus, contributing to the students' Bildung (Seel, 1999).

Altogether, this has led to a science education which students experience as exclusive and alienating (Brickhouse, 2011). However, the lack of willingness to participate in science education cannot be blamed on the individual student; this must rather be considered as a challenge for science education and curriculum (Brickhouse, 2011).

Because chemistry education has been struggling with its relevance to young people's lives, it is important to investigate how traditional chemistry content can be taught through activities where students are given the opportunity to experience chemistry as related to their own lives. To present a more diverse image of science, more research is needed on how we allow students to experience chemistry as open and tentative, and with possibilities for more than one explanation.

Authenticity in chemistry education

Different aspects and meanings of the concept authenticity have been extensively discussed in science education research (Anker-Hansen & Andrée, 2019). One of these aspects is personal authenticity, which is about opportunities for students to find value and meaning in what they are expected to do and learn (Murphy, Lunn, & Jones, 2006). Personal authenticity is about how students relate the subject matter content to themselves (Lundegård, 2018). According to previous research, connecting content to students' everyday lives is considered fundamental for enhancing their perception of chemistry education as relevant (Aikenhead, 2006; Broman & Simon, 2015). Nevertheless, this connection is hard to make, and for students to develop meaningful chemistry content knowledge they need support to connect this knowledge to their everyday lives (Childs, Hayes & O'Dwyer, 2015; Sevian & Bulte, 2015).

Real-life issues are often uncertain and unpredictable, and the science needed to deal with them can be a complicated body of knowledge. Thus, the scientific theories learned in schools

are usually not applicable (Aikenhead, 2006; Roth & Barton, 2004). Brickhouse (2011) concludes: 'The knowledge taught in schools is often decontextualized, abstract and difficult to apply to real world contexts' (Brickhouse, 2011, p. 199).

Towards a participatory chemistry education

It is often claimed that science education relies on pedagogical methods that are irrelevant for students or their society (Hofstein et al., 2011; Lindahl, 2003). According to Brickhouse (2011), school should focus more on developing students' ideas in ways that are meaningful to them and less on preparing students to repeat what others have already said and done. This could possibly make science attractive for a more diverse group of students.

Basu & Calabrese Barton (2010) developed a model for democratic science education through a researcher-teacher-student collaboration. Both teachers and students emphasised the importance of increasing student authority in the classroom. This was articulated as freedom of speech, choices about their education, (e.g., field trips, assignments and decorations in the classroom) and to base activities on students' interests. The importance of connecting science to the students' real-life experiences was also emphasised, in order to make students' knowledge from outside of school part of science education. In particular, valuing students' funds of knowledge can improve classroom equity (Basu & Calabrese Barton, 2010). One way to pro-vide students with increased freedom of speech and make their voices worthwhile, is to present science as tentative, with opportunities to discuss different evidence-based opinions (Basu & Calabrese Barton, 2010). Here, the students can participate by sharing their own perspectives and knowledge. When students are encouraged to go beyond facts and take a critical stance to-wards the content it enables them to critically evaluate the knowledge in relation to real-life is-sues. Moreover, this presents a view of doing science which resembles a scientists' process of doing science. Basu & Calabrese Barton (2010) conclude that democratic education includes empowering students to show motivation and excellence in the science classroom.

Learning science is not only about learning new concepts, theories or methods, but also about understanding a new subculture and the development of a new language (Lemke, 1990). Aikenhead (1996) argues that we cannot expect participation in one subculture to prepare students for participation in other subcultures. The different subcultures must be allowed to merge. How-ever, one common view is that this is a process of assimilation, i.e., that there is a conflict be-tween the students' everyday experiences and scientific knowledge, and that the students should abandon their previous perspectives to adapt to the scientific world views (Calabrese Barton, Tan & Rivet, 2008). One perspective which attempts to merge the subcultures of school science and everyday life is described by Calabrese Barton et al., (2008) as *hybrid spaces*. In these spaces, multiple knowledge and discourses come together, to be tried and challenged. Both scientific and everyday knowledge are mutually transformed, and new knowledge and discourses are created:

> The third space, or hybridity, therefore, sheds light on science learning because it offers a way of understanding how learning science is as much about learning to negotiate the multiple texts, discourses, and knowledges available within a community as it is about learning particular content and processes (Calabrese Barton et al., 2008, p. 74).

Calabrese Barton et al. (2008) argue that through activities which draw on a diversity of entry points and resources, students' funds of knowledge can be made worthwhile. These activities can also be a way to challenge and transform both scientific and everyday knowledge, and a way of understanding how these overlaps inform each other. Students and teachers can be sup-

ported in moving towards discourses and activities that favour new forms and spaces for meaningful participation. While teachers have an important role in constructing these activities, the development of hybrid spaces is always a collaboration between students and teachers.

Participation in hybrid spaces also relates to the shared teacher-student authority in the classroom (Basu & Calabrese Barton, 2010), thus enabling a redefinition of students' participation and the teachers' role:

> It is in these hybrid spaces where teachers' structural and pedagogical choices allow them to share authority with their students—allowing students to take on, however momentarily, the identity of an expert rather than a novice—and where students can feel what they have to contribute matters and is of value (Calabrese Barton et al., 2008, p. 98).

To conclude, research shows the importance of a science education presenting science as tentative and allowing different discourses to merge. Clearly, further research needs to explore how authentic activities in chemistry education can be created to enable students to participate in hybrid spaces, allowing new ways of student participation to emerge. These activities should enable students to connect their everyday experiences to science content knowledge and to participate with their own funds of knowledge.

Complex issues and complexity in science education

The notions of *complexity* and *complex issues* are widely used in science education research and science curricula. The meaning or definition of complexity is, however, rarely clarified. According to the Cambridge Dictionary, complexity can be defined as 'the state of having many parts and being difficult to understand or to find an answer to'. In a comprehensive review of complexity theory research, Rucker and Geronimo (2017) argue that complexity 'refers to an inter-play of components, that underlies an open and uncertain dynamic, and thus possesses serious planning and governance problems' (Rucker and Geronimo, 2017, p. 572). Furthermore, they argue that '[t]o investigate a subject in its complexity thus means above all to focus on the inter-play of components, and to clarify how these elements interact' (Rucker & Geronimo, 2017, p. 572). The dynamic of complex subjects is described as open to the future, where the future is understood as an infinite space of possibilities. The dynamic, therefore, is not only seen as open, but also as uncertain: 'Complexity science has taught us to expect the unexpected' (Rucker & Geronimo, 2017, p. 573).

Complexity in chemistry education has mostly been discussed in relation to socio scientific and environmental issues. The analysis of complexity is commonly connected to the issues themselves, i.e., as the inherent complexity within the issue. This has, for instance, been analysed in terms of how the students perceive this complexity (e.g., Sadler, Barab & Scott, 2007). A different approach towards complexity is described by Knain (2015), where the focus is not on the issue itself, but on the complexity as it evolves in the students' discussions: 'We understand complexity as a quality of the unfolding discourse rather than an inherent characteristic of the issue' (Knain, 2015, p. 113). In this thesis I will draw on Knain's (2015) approach to complexity, i.e., as a quality which unfolds in the students' discussions.

Approaches to complexity and complex issues in science education

Sustainability issues

Chemistry content knowledge plays a key role in empowering students to participate in the debates and decision-making required for acting towards a sustainable future (Chang Rundgren & Rundgren, 2015; Childs et al., 2015; Eilks & Hofstein, 2015). However, for chemistry knowledge to become relevant for sustainable development, scientific content knowledge on its

own is not enough. Educational activities must be designed in such a way that it gives students opportunities to develop competences which enable them to participate in discussions where chemistry content knowledge is required (Burmeister et al., 2012; Sjöström, Rauch & Eilks, 2015). However, a review of science education in Israel, Germany and the US showed that students were seldom given opportunities to participate in such discussions (Hofstein et al., 2011).

Previous research has shown the importance of enabling students to pay attention to the inherent complexity in sustainability issues (Simonneaux, 2008; Öhman, 2008; Öhman & Öhman, 2012). Within pluralistic environmental education, sustainability issues are viewed as conflicts between different interests, values and perspectives (Öhman, 2008). There are no predetermined right answers or ways of acting; rather, we must each argue for the choices we make (Rudsberg & Öhman, 2010). Moreover, education must aim to strengthen the students' action competences (Jensen & Schnack, 1997); for instance, through a making the conflicts and values inherent in the issue at hand visible.

Socio scientific issues

One common approach to sustainability and complex issues in science education is Socio Scientific Issues (SSI). SSI can be described as scientific issues that have a potentially significant impact on society (e.g., Chang Rundgren & Rundgren, 2010; Sadler & Zeidler, 2005). These issues often relate to environmental issues and are authentic and contemporary (Ratcliffe & Grace, 2003). SSI require reasoning and decision-making, where scientific knowledge, social aspects and values inform the students' arguments and choices (Aikenhead, 1985; Chang Rundgren & Rundgren, 2010; Simonneaux, 2008). Simonneaux argues that '[a]n important aim for science educators is to teach science content not only for students' learning of science, but above all to empower them in their decision making in their lives' (Simonneaux, 2008, p. 180).

SSI are controversial issues which involve multiple stakeholders with different perspectives; hence, issues that are complex, open-ended and debatable, which also relate to their inherent uncertainty (Simonneaux, 2008). The notion of *wicked problems* is relevant here—issues which are unstructured and difficult or impossible to solve due to the contradictory, uncertain, incomplete or changeable nature of the content knowledge (Weber & Khademian, 2008). These problems are also permeated with different stakeholders' perspectives on the issues' potential solutions (Kreuter, De Rosa, Howze & Baldwin, 2004). Both SSI and wicked problems are issues that embody hard-to-disentangle facts, cause and effect, and where there is a lack of agreement regarding problems and solutions. Furthermore, these issues are permeated with different value-based perspectives and conflicts of interests.

Previous research has shown that SSI increase students' interest in science and their scientific literacy (e.g., Chang Rundgren & Rundgren, 2010). SSI have been shown to be useful in improving scientific content knowledge (Sadler et al., 2007; Simonneaux, 2008) and the content knowledge developed through SSI 'becomes personally relevant and socially shared' (Sadler, Romain & Topcu, 2016, p. 1623). SSI can also contribute to creating need-to-know situations in science (Bulte, Westbroek, De Jong & Pilot, 2006). Simonneaux (2008) claims that SSI can support students in dealing with complexity.

Context Based Learning

Another common approach to complex issues in chemistry education is Context Based Learning (CBL). This approach often focusses on the scientific content more than the societal aspects of the issue, and context based chemistry aims to connect the chemistry content knowledge to SSI (Pilot & Bulte, 2006). An additional purpose is also to focus on a few key concepts within the chemistry curriculum, and to avoid the traditional content overload (Bulte et al., 2006; Pilot & Bulte, 2006). Context based education involves starting from a problem within a context, and

from there guiding the students through chemistry-related challenges towards a solution to the problem. During this process, the students are expected to request and learn chemistry knowledge on a need-to-know basis. Furthermore, the context is supposed to frame the scientific concepts in a meaningful way (Bulte et al., 2006). However, it is essential that the context is chosen and designed from the students' interests and need-to-know perspectives (Bulte et al., 2006). Another challenge is that the scientific theories must fit within the context in a meaningful way, otherwise there is a risk of losing the science in the context (Parchmann, Gräsel, Baer, Nentwig, Demuth & Ralle, 2006; Sevian & Talanquer, 2014). Previous studies have shown that context based chemistry is a viable approach to increasing student interest and motivation (Broman, Bernholt & Parchmann, 2018).

In summary, research shows the importance of learning science in a cultural and social context to contribute to scientific literacy and Bildung. In this thesis, I analyse two different contexts in chemistry education. In the first study, we analyse activities based on content which is usually conveyed through a Vision II perspective. In the second study I analyse how chemistry content, often designed from a Vision I perspective, can be taught through an activity which is based on a Vision II perspective. Students are thereby enabled to use chemistry content knowledge to resolve common societal issues.

Methodology

This section presents my research approaches and analytical methods along with the pragmatic perspective on learning and meaning-making upon which this thesis is based.

Didactics

The term didactic originates from the Greek word *didaskein*, meaning to teach or to educate. The European usage of didactics originates from 17th century Germany (Wickman, 2014). There is no consensus on what constitutes didactics, nor agreement on what the term means (Künzli, 2000). However, the following three didactical questions can be used to frame the challenges didactics aims to address (Sandell et al., 2003; Wickman, 2014):
What content is to be taught? How is this content going to be taught? Why teach this content and why with these methods? This last question regards the overarching purpose of education. One the one hand, the perspective that the school's primary purpose is to conserve and reproduce values and knowledge. On the other hand, the perspective that the main purpose of education is to critically question the prevailing conditions to contribute to changes in society.

Didactic research aims to support teachers' reasoning and decisions regarding these questions. Didactics can be understood as the professional science of teachers: 'Didactics provides the professional teacher with a tool for a critical analysis of teaching targets and teaching contents' (Seel, 1999, p. 89). Wickman (2014) argues that teachers should also actively participate in public debate about schools and curricula: 'This is why a science of didactics is needed, and this is the primary purpose of didactics— to share such systematic grounds beyond established prescriptions and traditions' (Wickman, 2014, p. 146).

Didactics has a close connection to the Bildung tradition and this relationship has resulted in didactic models aiming to support teachers' didactic design and analysis in relation to the didactic questions above (Duit et al., 2012; Ingerman & Wickman, 2015; Wickman, 2014).

Didactic modelling

Didactic modelling is a practice-based method and builds on a close cooperation between didactic theory and practice. A didactic model aims to be useful for teachers in didactic analysis and design, and is a further refinement of what teachers already know and do (Duit et al., 2012; Ingerman & Wickman, 2015; Wickman, 2014).

Didactic modelling consists of three phases, *extraction, mangling* and *exemplification* (Wickman, Hamza & Lundegård, 2018). However, these phases are often intertwined and performed simultaneously. Extraction consists of studying classroom activities where processes of interest for didactic modelling are going on. In this phase, empirical data is collected and teacher and student knowledge and classroom processes are described. During this phase, learning theories are pro-cessed with the empirical material to extract the model. The extracted didactic models are often conceptualised with a conceptual scheme (Wickman, 2012).

Mangling is the process whereby the previously extracted model is applied in practice for refinement. An extracted model and its conceptual scheme must be tested in practice. Through

mangling, the model's usefulness and limitations can be analysed. One purpose of mangling is to see how it can be useful for teachers' practice of didactic analysis and design. The processes of extraction and mangling are often performed simultaneously in cyclic interventions.

In the exemplification phase, the model is used in different contexts, e.g., different subject matter contents or different age groups, to test its usefulness and limitations.

In didactic analysis, the didactic models can be used to analyse how certain educational activities respond to specific purposes and objectives. A useful model supports the teacher in explaining why particular processes had certain consequences or outcomes. A didactic model also sup-ports the teachers in their planning and teaching. However, didactic models do not aim to produce complete models or describe 'best practice'.

Didactical research cannot only be presented to teachers, but must also be processed together with teachers (Ingerman & Wickman, 2015). One approach to closer cooperation between research and practice is to include teachers in the processes of exemplification. In the integrated work between researchers and teachers in developing didactic models, the borders between the teachers and the researchers become blurred (Ingerman & Wickman, 2015).

Didactic modelling has previously been used in several studies in science education. Johansson & Wickman (2018) developed the didactic model of organising purposes, to support teachers in the development of a progression between the proximate purpose, which is the student-oriented purpose, and the ultimate purpose, which is the teacher's and curriculum's purpose. This model was further exemplified in a study conducted in context based science education context (Lavett Lagerström, Piqueras & Palm, 2018). Pihl (2019) shows how organising purposes can be used by teachers to design learning activities that enhance students' meaning-making in socio scientific issues. In another recent study, Eriksson & Lundegård (2018) extracted a didactic model called *Didactic model for discursive feedback* in a socio scientific context, aiming to analyse teachers' responses to students' utterances and how these different responses changed the classroom discourse. Three different categories of responses emerged: maintaining, hybridisation and reorganising.

Drawing on previous research, I conclude that didactic models are used and appreciated by teachers. However, didactic models are context based, and different contexts need their own special models; so a diversity of models is needed. Accordingly, I aim to contribute to the field with didactic models for complexity in students' discussions in chemistry education (papers I and II). In the first study in this thesis, we conduct an extraction of what constitutes complexity in students' discussions regarding a sustainability issue (Dudas, Rundgren & Lundegård, 2018). In the second study we conduct a mangling of the previously extracted model in a new context, i.e., metabolism in the human body (paper II).

Design Based Research

The first study (paper I) in this thesis was conducted as Design Based Research (DBR). DBR is practice-based research approach that aims to increase the relations between educational research and teaching and learning in practice (Andersson & Shattuck, 2012; McKenney & Reeves, 2014). In DBR, both researchers and teachers are active participants in producing fruitful changes in education (McKenney & Reeves, 2014; The Design Based Research Collective, 2003). DBR draw on challenges identified by teachers in their own practice, making close collaboration with teachers essential. The local context informs which challenge should be addressed and what questions should be asked. DBR aims at both developing practice in schools and generating new theory (McKenney & Reeves, 2014).

A design study includes an intervention which is planned, conducted and analysed in cycles. In the first cycle, the educational activity is planned from tentative design principles and the

analysis of the teaching and learning guide the refinement of the design principles. Hence, between each cycle, changes are made to develop and refine the design principles for the next cycle (The Design Based Research Collective, 2003). However, the purpose is not to produce final principles, but to develop principles which can be further refined in practice. The study presented in paper I was conducted in two cycles aiming to develop design principles for activities in chemistry education supporting students to make complexity in sustainability issues visible (Dudas et al., 2018).

As one of the objectives of this thesis is to contribute to the field with useful tools for practice, DBR seemed like a viable approach for the first study. DBR has previously been success-fully used in practice-based research. Enghag & Schenk developed design principles for learning activities that addressed nanotechnology and risk assessment (Enghag & Schenk, 2016); and in another study, design principles for activities that aimed to develop students' capabilities to critically reason in science education were developed (Wiblom, Rundgren & Andrée, 2017). In a recent study, design principles for creative drama in chemistry education were developed (Danckwardt-Lillieström, Andrée & Enghag, 2018). However, there seems to be a lack of design studies which explore complexity in students' discussions in chemistry education. I chose, therefore, to conduct DBR to develop design principles for activities aiming to make complexity in sustainability issues, in chemistry education, visible (Dudas et al. 2018).

Didactic modelling and DBR—similarities and differences

Methodologically, didactic modelling and DBR share some characteristics. Both methods emphasise close collaboration with teachers, are conducted iteratively in cycles and aim to simultaneously develop both practice and theory. However, there are also some differences. An overarching aim for didactic modelling is to develop didactics, and through didactic models contribute to the development of the professional science of teachers. Thus, the extracted models can be a tool for developing a common language for teachers, teacher educators and educational re-searchers. In DBR the anticipated outcome are design principles. Design principles are often more specific than didactic models. In relation to the didactic questions: *What? How?* and *Why?* didactic models can support teachers regarding the *what* and *why* questions. However, design principles are about *how* to teach content (Wickman et al., 2018). I consider didactic modelling and DBR to complement each other. I chose didactic modelling and DBR as research approaches because of the close teacher-researcher collaboration and my intention to develop tools to improve teaching and learning in practice.

Theoretical framework

Pragmatic perspective

The pragmatic perspective on knowledge, learning and meaning-making is based on John Dewey's work. A pragmatic perspective means that learning and meaning-making are situated activities. Meaning-making involves communicative actions where encounters with other people (e.g., other students or the teacher) and/or physical things (e.g., practical work, textbooks or instruments) are essential (Wickman, 2014; Wickman & Östman, 2002a). The concepts of meaning-making and learning are often used synonymously. However, meaning-making is often regarded as a broader concept and can be used to emphasise that learning is not limited to learning con-tent knowledge, but also includes a process of socialisation and inclusion of companion values (Lidar, 2010).

In the process of learning something new, one departs from earlier experiences relevant to the current situation. Dewey (1929/1958) uses *re-actualisation* to describe the process of connecting previous knowledge to new ways of participating. This new way of participating can be regarded as transformed knowledge, and learning can be viewed as a transformation of experiences. Rudsberg & Öhman write: 'we see meaning making as indissolubly connected to action, and therefore, define meaning making as a process in which individuals create relations between earlier knowledge and the present situation' (Rudsberg & Öhman, 2015, p. 956). However, because it is only when students value the activity that they are able to incorporate it into their previous experiences, education must offer activities based on what the students already know (Wickman, 2013). According to Dewey (1916/2004) knowledge can be seen as participation:

> If the living, experiencing being, is an intimate participant in the activities of the world to which it be-longs, then knowledge is a mode of participation, valuable in the degree in which it is effective. It cannot be the idle view of an unconcerned spectator (Dewey, 1916/2004, p. 323).

This also means that knowledge exists when it appears and becomes useful in a context (Cherryholmes, 1999). Since knowledge gets its meaning through the activity, then learning something means it must also be used in an activity where it is needed (Cherryholmes, 1999). Thus, knowledge is something we do, rather than something that happens inside one's mind: 'Meaning is not indeed a psychic existence; it is primarily a property of behaviour...' (Dewey, 1929/1958, p. 179).

An essential pragmatic perspective is that the meaning of knowledge can be found in its consequences. Previous experiences become useful in activities where they are processed and tried out, to see how to proceed in the activity in a fruitful way. This means that knowledge is not merely put together, but is also investigated to see what consequences it brings to our actions. In an activity, the consequence can be viewed as the direction of the communication where meaning-making is a forward-directed movement (Dewey, 1929/1958). Furthermore, what can be regarded as useful knowledge and action cannot be determined in the present. As today's experiences are transformed in forthcoming activities, the future consequences will tell the quality of today's actions (Dewey, 1916/2004; 1938/1997; Wickman & Östman, 2002a). Nevertheless, this does not mean that we learn things now for future use. Dewey writes:

> We always live at the time we live and not at some other time, and only by extracting at each present time the full meaning of each present experience are we prepared for doing the same thing in the future. This is the only preparation which in the long run amounts to anything (Dewey 1938/1997, p. 49).

From a pragmatic perspective, learning subject content matter is inseparable from learning values. The students do not only learn facts and theories, but also whether they like the content or not (Dewey, 1938/1997; Wickman, 2004). The students are constantly making decisions about how to proceed, how to act and what to focus on. Therefore, a value free education is hard to imagine (Wickman, 2004).

According to Dewey (1938/1997) obstacles are an important part of the development of new thinking and should not be avoided. This inevitably introduces uncertainty and situations which cannot be foreseen. Dewey (1938/1997) argues that encounters with the unpredictable and still-unknown establish 'an active quest for information and for production of new ideas' (p. 79). He continues: 'new facts and new ideas thus obtained become the ground for further experiences in which new problems are presented' (Dewey, 1938/1997, p. 79).

In this thesis, I am empirically investigating how students are enabled to process chemistry knowledge in activities where it is needed and how this supports the students in progressing through the activity. I also aim to investigate how uncertainty and the still-unknown challenge

the students to explore the chemistry content and how this relates to participation. It becomes particularly important to analyse participation as it is closely related to doing, which from a pragmatic perspective is regarded as one pivotal aspect of knowledge.

Analytical approach

In this thesis I have used Practical Epistemology Analysis (PEA) and Deliberative Educational Questions (DEQ) as analytical tools, both of which are based on a pragmatic framework.

Practical Epistemology Analysis

PEA was developed by Wickman & Östman (2002b) to analyse students' interactions in classroom activities. The focus in a PEA is the students' communicative actions, including both what is said and what is done. PEA has mostly been used to analyse students' learning and meaning-making in discussions. However, the unit of analysis is not the individual student's utterances but rather the mutual transactions in the discussion. The individual utterances are not analysed as separate indications of knowledge (Lundegård & Wickman, 2007).

Five concepts are central in a PEA: *Purpose, stand fast, gap, relation* and *encounter*. The purpose is that which the students are expected to do and learn during the activity. The encounters might be with physical artefacts (e.g., the textbook, movies or laboratory material) or interactions with other people (e.g., students, teachers or a scientist). What stands fast will emerge as the things that are not questioned or explained in the transactions. All communicative actions are based on points that stand fast between the participants in the activity.

Gaps describe what needs to be disentangled before moving on in the activity. Relations are construed to fill the gap, i.e., to relate what one already knows to things that were previously unknown. The gaps are discerned through the construed relations. When a gap is filled, previous experiences are transformed and something new is learned which is needed to deal with the activity. The encounters are important for the kind of gaps that emerge, and, thereby, for the relations that will be created.

To conclude, the notions stand fast, relation and gap are about how the transactions unfold and how previous experiences connect to new ways of dealing with the activity. However, learning is not about remembering all gaps and relations, but rather a new way of handling the situation (Wickman, 2004; 2013).

Deliberative Educational Questions

A further development of PEA is Deliberative Educational Questions (DEQ) (Lundegård & Wickman, 2007; 2012). This analytical method involves rephrasing the gaps and relations which emerge in an activity into deliberative questions. These deliberative questions represent the considerations which the students need to deal with to move on with the activity. DEQ was developed to analyse conflicts of interest in sustainability issues (Lundegård & Wickman, 2007; 2012). In this thesis we use DEQ to make visible the considerations the students introduce in relation to the chemistry content. Therefore, we do not specifically focus on sustainability issues or moral issues, but rather explore how DEQ can be a useful analytical method to analyse different kinds of content and considerations, e.g., factual and morals-related content.

A student's utterance in a discussion gives the other participants something to expand on and the opportunity to raise their own voices and connect the chemistry content to their own considerations and experiences. Previous research shows how a person's utterances can challenge and enable others to 'take new initiatives in the deliberation' (Lundegård & Wickman, 2012, p. 165) and how this encourages students to suggest new ideas.

How PEA and DEQ are used in this thesis

I illustrate how PEA and DEQ were used with the excerpt below. Three students are participating in a discussion. The purpose of the discussion is to compare the pros and cons of microwaved popcorn and stove-made popcorn. The problem with microwave popcorn is that the packaging normally contains perfluorinated chemicals which might contaminate the popcorn.

1. Elin: But I also think, what is a harmful dose? It's not a lot in one bag, is it?

Here a relation is established between the amount of perfluorinated substances in the bag and a harmful dose. This gap can be formulated as the DEQ: *Is the dose you are exposed to harmful, or not?*

2. Frida: No exactly, and our conclusion was that the amount in microwave popcorn is so small that a normal consumption of popcorn, like, if you eat once a week, then it is not harmful for your health.

Here a relation is established between 'normal consumption' and 'not harmful'. This gap can be formulated as the DEQ: *Is it harmful if you eat popcorn once a week?*

3. Elin: But it becomes a problem if you eat it every day?

Here a relation is established between 'consumption everyday' and 'harmful'. This gap can be formulated as the DEQ: *Is it harmful if you eat popcorn every day?*

4. Frida: Yes, and it often gets into the environment.
5. Elin: Yeah, I thought about that too.

Here a relation is established between 'PFOS in products' and 'environmental problems'. This gap can be formulated as the DEQ: *Is one of the problems with using products containing PFOS that it eventually reaches the environment?*

6. Jonas: Yes, and then it is bioaccumulated. I suppose the ecological would be the largest issue regarding perfluorinated substances.

Here a relation is established between 'Bioaccumulation' and 'largest problem'. This gap can be formulated as the DEQ: *Is the biggest problem with using products containing per-fluorinated substances the risk of bioaccumulation?*

7. Elin & Frida: mm, yes.

Note that the term 'or not' at the end of the first DEQ above implies that this a question of choice. We assume the 'or not' question to be implicit in all the DEQ presented.

The excerpt above also shows how the students are given opportunities to expand on their own and the others' utterances. They start by discussing a harmful dose and end up discussing bioaccumulation as the biggest problem.

Settings and participants

Below, I present the participants in this study and how the data was collected before discussing the students' activities and how these developed through the studies. Finally, I describe the Swedish curriculum for upper-secondary school chemistry.

Participants and empirical data

This thesis is based on three cycles conducted at two upper-secondary schools in Stockholm during a two-year period (Table 1). The participating students were enrolled in the Natural Science programme. All cycles were conducted as a part of regular chemistry classes, i.e., all students in the classes participated in the activities. However, for practical reasons, only a limited number of groups of students were recorded on video (Table 1). The recorded groups worked in separate rooms, with one camera in each room. The recorded groups consisted only of students who had agreed to be recorded. While the groups were put together by the teachers, I requested that the groups should be heterogenic to reflect the diversity among the students in the class.

Table 1. Participants and empirical material

	Study one (Paper I)		Study two (Paper II)
	Cycle one	**Cycle two**	**Cycle three**
Content	Electrochemistry: batteries	Environmental chemistry: organic pollutants in everyday life	Biochemistry: metabolism in the human body
Schools	One upper-secondary school, school A	Two upper-secondary schools, school A and B	One upper-secondary school, school B
Course, Grade	Chemistry 1, 2nd year	Chemistry 2, 2nd and 3rd year	Chemistry 2, 3rd year
Number of students	60 students	111 students	56 students
Number of teachers	2 + myself	2 + myself in school A, 1 + myself in school B	3 + myself
Recorded groups and students	3 groups with 3–5 students, totally 12 students	11 groups with 3–4 students, totally 38 students	3 groups with 4–6 students, totally 15 students
Recorded material	2 hours	10 hours	30 hours

The first and second cycles were conducted at Schools A and B. At the time cycle two was conducted in School B, I was also one of the chemistry teachers at the school. Hence, I had the double role of both researcher and chemistry teacher. However, during the classes which were part of my research there was always another teacher doing the teaching. I was merely responsible for the research and data collection. At School A I only participated as a researcher. In both cycles one and two there was close collaboration between me and the chemistry teachers in the development and teaching of the student activity.

While the second study was conducted at School B where I had previously worked as a chemistry teacher, the participating students had never had me as a teacher. During this study I

worked closely with three chemistry and biology teachers to develop and conduct the students' activity.

The students' activities

Study one was conducted as an in-situ didactic modelling and design study with two cycles. In the first cycle the students' activity was about batteries and electrochemistry. The students worked in groups with different types of batteries and at the end of their projects they had discussions in intergroups about which battery to choose for different products: a 'smart T-shirt', 'smart spectacles', and a space rocket.

In the second cycle the chemistry content and the design were completely different. In this cycle the students worked with organic pollutants in everyday products. In the discussions the students choose one everyday product containing an organic pollutant and compared it to a similar product without the pollutant (e.g., microwave popcorn vs. stove-made popcorn, or outdoor clothes with Gore-Tex vs. outdoor clothes without Gore-Tex). The discussions in cycles one and two were recorded on video and all relevant parts were transcribed and analysed.

Study two was conducted as an in-situ study with one intervention. This study was not part of the design study performed in study one. However, we chose to name it cycle three since the previously extracted didactic model was mangled in a new context. To clarify, it was the third cycle in the didactic modelling, but not part of the design study in paper one. In study two, the students worked with human metabolism, specifically the level of glucose in blood and the different factors influencing these levels. During this activity the students conducted laboratory work where they ate various foods, i.e., fast carbohydrates, slow carbohydrates or fat and measured their blood glucose levels over the next two hours. During the following classes they analysed their data and made a scientific poster presenting their results. All these activities were recorded on video and all relevant discussions were transcribed and analysed.

In this thesis, I use *chemistry content issue* to describe issues where the focus is the chemistry content, rather than the societal perspectives on the issues.

Study design

In the analysis of the first cycle, I found the students' discussions somewhat basic and they did not try to problematise the issues they were discussing. When I tried to understand why this was the case, I realised that there was a lack of complexity. The students did not make the complexity within the issue visible. This is the background for our approach towards complexity, and the focus on complexity in this thesis.

Cycles one and two were part of the design based study. In cycle one, we departed from tentative design principles based on previous research and the participating teachers' experiences regarding pluralistic perspectives on environmental issues. These principles were refined in cycle two.

When I prepared the third cycle, I realised that most of the research regarding students' participation, science education for citizenship, and complexity was conducted in socio scientific or environmental issue contexts. As there seems to be a lack of research regarding how chemistry content issues can contribute to science education for citizenship, I became interested in analysing how education can be designed to allow these perspectives to unfold.

We wanted to focus on a chemistry content issue in study two, so we choose not to use the design principles developed in study one. The activity in cycle three is an activity which has been continuously developed and refined over a 10-year period by the teachers in School B.

The development has been conducted through an analysis of previous research, students' meaning-making and the teachers' experiences.

The didactic modelling was conducted through the three cycles. The first didactic model (paper I) was extracted through an analysis of cycles one and two in the first study. In the second study (paper II), we aimed to mangle the model through an analysis of its applicability in a new context. The analysis resulted in a refined model, partly overlapping with the previous model.

In the first study (paper I) we draw on a pluralistic perspective on sustainability issues, and assume complexity to consist of: areas where chemistry knowledge is required to understand the issue and its potential solutions; where conflicting perspectives and values permeate the issue; and where there is an uncertainty relating to the facts, which, together with conflicting perspectives and values, makes the issue incomplete and contradictory. In the second study (paper II), which is based on a chemistry content issue, we assume complexity to include attempts to discern how different factors interact and are closely related to uncertainty. In both paper I and paper II we were analysing the complexity as it unfolded in the students' discussions.

Swedish chemistry curriculum

The Swedish curriculum for upper-secondary school chemistry consists of four levels: overarching aim, knowledge and abilities the students are supposed to develop, core content and grade requirements. Chemistry is divided into two courses: Chemistry 1 and Chemistry 2. The overarching aim describes overall aspects of chemistry knowledge and the relations between chemistry content knowledge and the world around us:

> Teaching should also help students develop their understanding of the importance of chemistry for climate, the environment and the human body, knowledge of different applications of chemistry in areas such as the development of new medicines, new materials and new technologies. Teaching should give students the opportunity to develop a scientific approach to the surrounding world. Teaching should take advantage of current research and students' experiences, curiosity and creativity. Teaching should also help students participate in public debates and discuss ethical issues and views from a scientific perspective (Swedish National Agency for Education, 2011).

The core content aspects specify the chemistry content, e.g., 'Redox reactions, including electro-chemistry'; 'Different categories of organic substances, their properties, structure and reactivity'; and 'Biochemistry—the main features of human metabolism at the molecular level'. Relations to environment and sustainable development are also mentioned, e.g., 'Determining views on social issues on the basis of chemical models, e.g., sustainable development issues'; and 'Is-sues concerning ethics and sustainable development linked to different ways of working in chemistry and activity areas' (Swedish National Agency for Education, 2011).

Furthermore, the grade requirements also contain content-related writings e.g., the term *complex issues* only appears in the section on grades. The requirements that mention complex issues for grade A are:

> Students analyse and look for answers to complex questions in familiar and new situations with good results. … Students discuss in detail and in a balanced way complex issues concerning the importance of chemistry for the individual and society. In their discussions, students put forward well-grounded and balanced arguments and give an account in detail and in a balanced way of the consequences of several possible viewpoints. Students also propose new issues for discussion (Swedish National Agency for Education, 2011).

As can be seen in the examples above, the curriculum is open and written generically, with a large degree of freedom given to the teacher to choose the content and design the education.

Methodological and ethical considerations

Below I present and discuss the study's validity and generalisability as well as ethical considerations.

Methodological considerations

Validity

In qualitative studies, validity relates to how the interpretations of the data are clarified and explicitly justified (Coe, 2012). In this study I have tried to be explicit by presenting different excerpts that clarify how the students' discussions developed. I have tried to be transparent in the analysis about how I interpreted and categorised the DEQ. Validity relates to the conclusions one can draw from the empirical data. Therefore, I have tried, through the chosen excerpts, to show relevant connections between the empirical data and the conclusions (Wolcott, 1994). The excerpts, analysis and interpretations of the data were discussed with my two supervisors. Some of the excerpts, analysis and conclusions have been discussed with other researchers in seminars and at conferences. The excerpts were carefully chosen to exemplify different kinds of discussions and considerations.

Generalisability

It is sometimes argued that one cannot draw any conclusions from qualitative studies that are valid beyond the investigated situation. If this was true, it would decrease the interest for qualitative studies to more or less nil (Larsson, 2009). However, Wolcott (1994) argues that it must be possible to generalise, otherwise it would be meaningless to pay much attention to qualitative case studies.

Larsson (2009) discusses five different possible lines of generalisability in qualitative studies. One of these is '[g]eneralization through context similarities' (Larsson, 2009, p. 32). From this perspective, Larsson argues that results can be transferred to other situations if the contexts are similar. This kind of generalisation is also supported by Lincoln & Guba (1999) who argue that transference of results cannot be made by the author, but must rather be conducted by the reader. To give the reader opportunities to judge whether the results from one study can be valid in an-other context, the author must present a thick description of the researched context (Geertz, 1973). Only when the reader fully understands the original context can (s)he decide about the transferability of the results. In this thesis have I tried to give a thick description through detailed descriptions of the students' activities and settings. I have also presented several excerpts from students' discussions to give the reader insight into what was going on in the classrooms. Obviously, every classroom and every group discussion is unique, but the reader of this thesis can perhaps find interesting results which might be transferable to another situation.

Another of Larsson's (2009) lines of generalisation is '[g]eneralization through recognition of patterns (Larsson, 2009, p. 33) which he describes as 'an act, which is completed when someone can make sense of situations or processes or other phenomena with the help of the

interpretations, which emanate from research texts' (Larsson, 2009, p. 34). This includes empirical patterns which can be recognised in new cases by the reader: 'The reader is invited to notice something they did not see before' (p. 33). This generalisation also shifts the responsibility for generalisations from the researcher/author to the reader, who will be the one to judge whether a description is useful and applicable in another context. This line of generalisation moves beyond context similarities towards interpreting other cases with fewer similarities. If the pattern is recognisable then generalisation through recognising patterns can be made even if the contexts are different (Larsson, 2009). Larsson further argues that this line of generalisability is more realis-tic than generalisation through context, particularly when processes are studied. This also relates to naturalistic generalisability, which concerns the possibilities of a collateral influence on the reader, who might develop new insights or understanding of a phenomenon or process through previous research (Coe, 2012). One of the purposes of this study is to develop didactic models for teachers to use in didactic analysis. However, these are not meant to constitute complete models, but rather inspiration for teachers to further develop in their own settings as they recognise the patterns emerging in these models, e.g., when teaching other subjects.

To conclude, whether it is possible to generalise the results from the present study or not is up to the reader. It is my responsibility as an author to present a description thick enough for the reader to judge the value of the results in relation to his/her own context. It is my responsibility to describe and interpret the emerging processes and patterns in such a way that the reader might recognise them in future situations.

Ethical considerations and reflections

The research was conducted in accordance with the ethical principles set down by the Swedish Research Council (Swedish Research Council, 2012). All participating students and teachers were informed about their participation and the purpose of the project (the information requirement). They were also told that participation was completely voluntary, and about the possibility of withdrawing from the project at any time (the consent requirement). Students were informed that the data gathered would be treated confidentially, and no names of students, teachers or schools would be published (the confidentiality requirement). However, while, as mentioned, I am a teacher at one of the schools so it is always possible to find out the school's name, the years during which data was collected, has not been revealed. This makes it difficult to identify which classes and students participated. I also informed the students and teachers that only me and my two supervisors would have access to the recorded material. I informed them that the findings might be published in scientific journals and in a thesis, and presented at conferences (the requirement of restricted use). All this information was given to the students in a written document which they had to sign as proof of consent.

I would like to reflect on two ethical considerations which I encountered during my research. Firstly, the purpose of this study was partly to enable students to introduce their own ideas and questions, and to discuss issues from their own perspectives. It was therefore inevitable that sensitive or non-ethical utterances and personal information emerged at times. To safeguard the students' integrity and privacy, the published and presented excerpts were carefully chosen so as not to disclose students' sensitive opinions or reveal information that could in any way identify them.

Secondly, as I was both a researcher and a teacher in school B (the second cycle), and conducted the research with my own students, a reflection on student-teacher dependence is important. The students were informed that they would all be treated equally by me as a teacher, whether they chose to be recorded or not, and that the recorded material would only be used for

research and not for evaluating their chemistry knowledge. However, the thought that their consent might influence their relationship with me may have affected whether they consented to being recorded or not. This related not only to the recorded activity, but also to future activities, tests and grading in chemistry. This dilemma is multi-faceted, as the participating students had an opportunity to demonstrate their chemistry knowledge which the non-recorded students did not. However, the opposite is also possible—the recorded students may also have demonstrated a lack of chemistry knowledge which I had not been aware of prior to the recordings.

I dealt with this specific case in two ways. Firstly, I did not look at the recordings until after this specific unit was graded, to make sure that nobody would benefit or be penalised academically from participating in the study. Thus, in the grading situation I had no extra insight into the recorded students' work. Secondly, this unit was conducted midyear and I worked with the students subsequently and conducted the final grading at the end of the school year. Fortunately, at our school, we are two chemistry teachers working closely together throughout the course—planning, evaluating and grading. I thus let my colleague take the most responsibility for the recorded students.

A thorough knowledge about the context in which the study takes place is often regarded as a benefit in research (Andersson & Shuttrick, 2012). In this study, my previous experience from developing the analysed activities supported the process of further refinement of design principles and models. By starting with existing activities, we could better proceed with our research.

Results

Here I present a summary of the results from the two papers this thesis is based on.

Paper I

This study is based on two activities where the students were working on sustainability issues within a pluralistic educational tradition. The study was conducted as Design Based Research with two cycles. Didactic modelling was conducted simultaneously.

The first research question was: *What considerations can be discerned in students' discussions regarding sustainability issues in chemistry education?* This question was answered through an analysis of the students' discussions, using PEA and DEQ. The emerging DEQ were assumed to represent the considerations the students were dealing with in their discussions. Four categories of considerations emerged in the analysis: factual considerations with sufficient facts, factual considerations with insufficient facts, value-based considerations with sufficient facts, and value-based considerations with insufficient facts.

The second research question was: *How can a didactic model that aims to analyse complexity in students' deliberations be developed from these considerations?* The considerations emerging in the first analysis were used to extract the didactic model, which is represented in the conceptual scheme below (Table 2).

Table 2. Didactic model for analysis of complexity in deliberations regarding sustainability issues

Factual considerations Factual knowledge are required to deal with the consideration.	
With sufficient facts Factual knowledge is available	**With insufficient facts** Factual knowledge is not (yet) available for students, teachers or scientists.
Example: *Are highly fluorinated chemicals stored in our fat cells?*	Example: *Is the level of PFOA in microwave popcorn harmful or is the dose too small?*
Value-based considerations Factual knowledge, values and other experiences are required to deal with the consideration.	
With sufficient facts Factual knowledge is available	**With insufficient facts** Factual knowledge is not (yet) available
Example: *Are there any advantages of microwave popcorn compared to popcorn made on the stove?*	Example: *Should we consider the cocktail effect when discussing doses?*

The third research question was: *How can chemistry education be designed so that it enables students to make complexity visible in sustainability issues?* This question was answered through the development of the design principles. We analysed the following aspects of complexity: areas where chemistry knowledge is required to understand the issue and its potential solutions; conflicting perspectives and values permeate the issue; and, there is uncertainty about the facts, which together with conflicting perspectives and values makes the issue incomplete and contradictory. The study departed from two tentative design principles: (1) the students'

activity should include democratic deliberation to make the conflicts of interests and conflicting perspectives visible, and (2) the activity should be designed to require chemistry content knowledge to deal with the issue.

The analysis of the first cycle indicated that the tentative principles neither enabled the students to notice the conflicts permeating the issue, nor the uncertainty of factual knowledge. Only a few considerations dealt with conflicts and uncertainty. All these considerations emerged from the encounter with the frontier research algae battery. In an attempt to increase considerations regarding conflicts and uncertainty, the first design principle was revised for the second cycle. To enable the students to notice the inherent conflicts and uncertainty in the issues, the first de-sign principle was further specified to include the following in the students' activity: (1a) an explicit request for conflicting values and perspectives, and (1b) chemistry content knowledge based on frontier research.

The analysis of the second cycle showed that the students dealt with conflicting values and perspectives to a greater degree than did the students in the first cycle. Additionally, the results also indicated that the students noticed the inherent uncertainty and incompleteness within the issues.

Summary of results in paper I

Four different kinds of considerations emerged in the student's discussions which were used to develop a didactic model. Furthermore, three design principles were developed. These may be useful for designing activities that aim to make complexity visible in students' discussions regarding sustainability issues. The activity should be designed to (1a) include an explicit request for conflicting values and perspectives, (1b) include chemistry content knowledge based on frontier re-search, and (2) require chemistry content knowledge to deal with the issue and its solutions.

Paper II

Whereas students in the first study (paper I) worked with sustainability issues, in this study we analysed an activity where the students were working with a chemistry content issue, i.e., metabolism in the human body. The study was conducted as a classroom intervention. The students' activities consisted of a practical where they measured the level of glucose in their blood, followed by a discussion while they analysed their data.

The first research question was: *What kinds of considerations can be discerned in the students' discussions?* The students' discussions were analysed using PEA and DEQ. The analysis showed that two different categories of DEQ emerged from the students' discussions: factual and exploratory DEQ. We consider these DEQ representative of the students' factual and exploratory considerations. Factual considerations are questions with answers known by other students, teachers or experts. These considerations usually relate to the 'pure' chemistry content. Conversely, exploratory considerations are open with more than one possible answer or solution.

The second question was: *How will the didactic model for complexity in students' discussions evolve from a chemistry content issue?* We used the didactic model for complexity (Dudas et al. 2018) as an analytical tool. In the analysis we tried to merge the two categories of considerations in the present study into the previously extracted model. This analysis showed that the factual considerations could merge into the previous category *factual considerations with known answers*. The exploratory considerations share many attributes with *factual considerations with insufficient facts*. However, the in-sufficiency and uncertainty have different characteristics. The uncertainty in exploratory considerations is not within the scientific knowledge,

but rather in how to use the knowledge in real-life issues. Furthermore, it is often possible to further investigate exploratory considerations, which are also potentially a basis for investigable questions.

The analysis indicated that there was a lack of value-based considerations in the current context. We consider the value-related categories in the previous model (paper I) to be dealing with moral issues, i.e., how things ought to be or how we ought to act. There was an absence of moral considerations in the new context. A possible explanation might be that values and moral issues were not explicitly emphasised in this activity.

From the analysis in paper II, we propose the following model for complexity in students' discussions (Table 3):

Table 3. Didactic model for complexity in students' discussions

Factual considerations Considerations with answers known by others.	Exploratory considerations Considerations with more than one possible answer.
Example of DEQ representing factual considerations: *Does one absorb any energy when carbohydrates are digested in the mouth?*	Example of DEQ representing exploratory considerations: *Can Mark's unexpected level of blood glucose be explained by how he got to school?*

The third research question was: *In what ways can activities be designed to enable students to experience chemistry as exploratory?*

The results imply that chemistry can be experienced as exploratory through activities where students encounter unpredictable or inexplicable results. In the present activity this uncertainty emerged in situations where the students were trying to make the chemistry content knowledge useful in dealing with real-life issues. The students were thereby enabled to introduce exploratory considerations. As multiple answers or explanations become possible, these considerations enable the students to experience chemistry as exploratory. In dealing with exploratory considerations the students can then contribute with their own funds of knowledge. To conclude, drawing on real-life issues in chemistry education seems to be one way to enable students to experience chemistry as exploratory.

Summary of results in paper II

Two different kinds of considerations were discerned in the students' discussions: factual and exploratory considerations. These categories were then used to develop the new model for complexity in students' discussions. Basing chemistry education activities on real-life issues where the chemistry content knowledge is inherently uncertain can be one way to enable students to experience chemistry as exploratory.

Discussion

The overarching objective of this thesis is to explore how different contexts in chemistry education can contribute to science education for citizenship. This has been explored through two practice-based studies. These studies aim to contribute to the field with knowledge that is useful to practice and research relating to the complexity unfolding in students' discussions, and additionally, to explore how this can address some of the challenges regarding relevance that chemistry education faces. Through the two studies, didactic models for complexity in students' discussions were extracted and further mangled in a new context.

Chemistry as factual and tentative

The findings show how the students deal with different kinds of considerations in relation to the different chemistry content. In the first study (paper I), where the activities related to sustainability issues, four different kinds of considerations emerged: factual considerations with sufficient/insufficient facts, and value-based considerations with sufficient/insufficient facts. In the second study (paper II), which was about a chemistry content issue, two different kinds of considerations emerged: factual and exploratory considerations. The factual considerations in study one, and both kinds of considerations in study two deal with epistemological issues, i.e., how the world works. Factual considerations with known answers (paper I) and the factual considerations (paper II) are important for disentangling the chemistry content knowledge needed to deal with the other considerations. However, these considerations relate to the 'pure' chemistry con-tent and deal with known answers. They are in line with a Vision I perspective and thus a traditional perspective on science education (Sjöström et al. 2017). They might, therefore, contribute to preserving an image of science as absolute, having only one right answer, unaffected by values or cultural or societal perspectives (e.g., Aikenhead, 2006; Brickhouse, 2011; Roth & Bar-ton, 2004). In a Vision I tradition, students have often been expected, (and thus limited) to learn and repeat what teachers and other experts already know (Brickhouse, 2011). This has led to students feeling alienated, as chemistry seemed to be a subject with pre-determined answers and lacking creativity. Nevertheless, chemistry content knowledge is fundamental for scientific literacy (Roberts, 2007). Factual considerations must therefore be regarded as an essential part of chemistry education. However, an education that only focusses on known facts might preserve the idea of chemistry as non-exploratory, uniform and absolute.

Factual considerations with insufficient facts, value-based considerations with sufficient/insufficient facts (paper I) and exploratory considerations (paper II) allow the students to experience chemistry as tentative, as multiple solutions are possible. As neither the students nor the teachers nor other experts know the answers to these considerations, several theory-based explanations are possible and can be discussed. This can potentially contribute to a more diverse image of chemistry. A science education that includes these kinds of considerations can also contribute to democratic citizenship.

Basu & Calabrese (2010) suggest that presenting science as tentative, where students can participate with different evidence-based opinions can be a viable approach towards a participatory science education. It seems that exploratory considerations enable students to experience

science as tentative, as they facilitate discussions where different evidence-based perspectives are possible. In the second study, the students move on from what they already know, to create new knowledge in specific contexts where knowledge about metabolism is needed. I would like to stress that it is not about abandoning scientific knowledge, but rather about giving students opportunities to use and create their own knowledge in a specific context.

Complexity unfolding in students' discussions

Various perspectives on science education for citizenship emphasise science education as a tool for developing society for the good. This is especially emphasised in the Bildung tradition (e.g., Elmose & Roth, 2005). Furthermore, to change society in an ecologically and socially just way, a diversity of participants is needed in scientific practices (Brickhouse & Kittleson, 2006). To accomplish this science education must be designed in ways that support all students to develop both willingness and competence to participate in scientific practices aimed at changing society for the good. The results in this thesis imply that a science education that enables students to experience different kinds of considerations is one viable approach. The results also corroborate previous research which highlights the importance of complexity in science education for citizenship. The importance of introducing complexity has been highlighted within a pluralistic perspective on sustainability issues (Öhman & Öhman, 2012), and various studies have shown the importance of complex issues in science education generally. SSI has been shown to increase interest in science, to enhance students' scientific literacy, and to improve scientific content knowledge (Chang Rundgren & Rundgren, 2010; Sadler et al., 2007; Simonneaux, 2008). Context based chemistry has been shown to increase students' interest and motivation (e.g., Broman et al., 2018). However, studies also suggest that the complexity inherent in issues is often neglected, which might hinder students from developing as democratic citizens (Sund, 2015). The results from the first study in this thesis indicate that complex issues do not necessarily introduce complexity in the students' discussions, but rather that students need support to engage with complexity (paper I). Therefore, this thesis focuses on complexity as it unfolds in the students' discussions, and on designing learning activities which afford students' opportunities to grapple with the complexity within an issue. The factual considerations with insufficient facts, value-based considerations with sufficient/insufficient facts (paper I) and exploratory considerations (paper II) seem to be important for complexity as these introduce uncertainty into the discussions. Furthermore, these considerations seem to enable students to contribute their own everyday life experiences and funds of knowledge. These considerations can also facilitate hybrid spaces, allowing different discourses to merge. Here, both scientific and everyday life knowledge and discourses come together and transform each other (Calabrese Barton et al., 2008). Through hybrid spaces the teacher-student authority in the classroom can be transformed, and a meaningful student participation can evolve.

However, I would like to stress that I do not advocate an education based solely on students' interests. It is the teachers' responsibility to organise the education in accordance with the curriculum, to challenge the students, to enable them to create new experiences and discover interests which they might previously have been unaware of. The results in this thesis underline the importance designing activities that include students' interests in relation to the content.

Uncertainty and real-life issues

Previous research has stressed the importance of allowing students to experience uncertainty and unpredictability in real-life issues in science education (e.g., Aikenhead, 2006; Roth & Barton, 2004). Activities which draw on a Vision II perspective often lead students into areas of

uncertainty (Roberts, 2007). Dewey (1938/1997) also argues that encounters with obstacles should not be avoided, as these will inevitably introduce uncertainty. The (still) unknown should not be avoided, as it contributes to new thinking and the development of new ideas (Dewey, 1938/1997). The results in this thesis also underline the importance of encounters with uncertainty and unpredictability to allow complexity to unfold in the students' discussions. In the first study (paper I), it was the encounters in frontier research where we do not (yet) have enough knowledge which introduced uncertainty into the students' discussions. In the second study (paper II), the theories of chemistry knowledge were not unknown; both students and teachers knew theoretically how blood glucose level should have responded to different factors. Therefore, the uncertainty in this context is not in the scientific knowledge, but rather in how to use these known theories in relation to the real-life issue.

Real-life issues are not easy to comprehend as there are multiple factors influencing the processes, and the science traditionally learned in school is seldom useful for solving real-life issues (Aikenhead, 2006; Roth & Barton, 2004). The results in this thesis also stress the importance of drawing on real-life issues in chemistry education. An abundance of studies has highlighted the importance of connecting the chemistry content knowledge to students' previous experiences and everyday life (e.g., Aikenhead, 2006; Wickman et al., 2012). Previous research also shows the importance of including students' own questions, ideas and interests (Brickhouse, 2011). The results in this thesis indicate that in activities that allow students to introduce their own considerations, connections between the chemistry content and everyday life can be made. These activities can also contribute to the development of personal authenticity, as it relates to how the students can relate the subject matter content to themselves (Murphy et al., 2006).

Didactic models for complexity in students' discussions

In this thesis, a didactic model for complexity in students' discussions was extracted (paper I) and then further mangled (paper II). Didactic models always evolve from a specific context that will influence the model's appearance. Thus, the models include some context-specific aspects relating to complexity. In both studies, chemistry content knowledge is essential to disentangle how different factors interact, and thereby an important part of complexity. Uncertainty is also an essential element of complexity in both studies. In the first study (paper I) the uncertainty inherent in sustainability issues is essential for the unfolding complexity. This complexity is made visible through the factual considerations with insufficient facts, and value-based considerations with sufficient/insufficient facts (paper I). The second model (paper II) is based on a chemistry content issue. In this context, complexity also entails uncertainty, which is made visible through the exploratory considerations. These considerations are not about insufficient facts, but rather about how to make the chemistry knowledge useful when dealing with real-life is-sues. Exploratory considerations emerge when students encounter uncertainty which is related to making chemistry knowledge meaningful in real-life issues.

The first model (paper I) is based on a pluralistic perspective on sustainability issues. The value-based considerations in study one concern moral issues, i.e., how things ought to be or how one ought to act. From a pluralistic perspective, it is essential to make the inherent conflicts of interests visible and to allow students to participate in debates and argue for their own decisions (Rudsberg & Öhman, 2010; Öhman, 2008). Consequently, considerations about how one ought to act are an important part of the discussions, and an inevitable element of complexity related to sustainability issues. Although there was a lack of value-based considerations in the second study, from a pragmatic perspective, education is always permeated with values as the students learn not only content knowledge, but also whether they like the content or not (Dewey,

1938/1997). Learning activities are infused with choices which all include values, e.g., about what to focus on, how to act and how to proceed (Wickman, 2004). Therefore, we are not arguing that study two is value free, or that there is no room for values within this activity; the activity in study two did not explicitly deal with moral considerations.

The factual/exploratory model developed in the second study (paper II) is more general than the more specific model in paper I as the latter is based on the pluralistic perspective which permeates the model. I would, however, like to stress that the aim is not to produce complete models, but to propose models which may serve as a starting point and a support for teachers in the development of their own teaching. In future studies it would be interesting to mangle the factual/exploratory model and to analyse how it evolves in other contexts. Both DBR and didactic modelling contributed to the results in this thesis through their different outcomes. DBR contributed by providing design principles for the design of learning activities which aim to make the inherent complexity in sustainability issues visible. The didactic modelling contributed two models which can be used in the design and analysis of activities where complexity in students' discussions are preferable/desirable. The models developed in this thesis aim to support teachers in their designing of chemistry education activities and in their reasoning and decision making regarding the didactical questions: *What content to teach? How is this content going to be taught?* and *Why this content and these methods?* Therefore, in forthcoming studies it would be interesting to investigate how the models can support teachers in their designing of activities for complexity in chemistry education, and thereby the models' applicability in everyday practice.

Reflections

My experience as a teacher, and my role as both teacher and researcher in this project was important for the outcome of the study. It allowed a close relationship between the research project and some of the challenges I experienced as a teacher. Both studies in this thesis draw on challenges my colleges and I have encountered in practice. Hopefully, this thesis will contribute to other teachers' reasoning with regard to chemistry education for citizenship and complexity in students' discussions. However, for me as a teacher conducting research in my own classroom, there was the risk of allowing personal knowledge about the students to influence the results, e.g., only analysing discussions between carefully selected students, or only focusing on the outcomes I wished for. I therefore chose to conduct study one at two different schools. In one of the schools I had background knowledge of the setting and participants, but in the other I had none.

In the first study (paper I), we developed design principles for learning activities that would enable students to make complexity in sustainability issues visible. However, it was not possible to conduct study two as a DBR with more than one cycle. It would therefore be interesting in forthcoming studies to draw on the results in study two to conduct a design based study to develop design principles for learning activities that enable students to experience chemistry as exploratory. Two tentative design principles could be derived from the present study (paper II): activities should be based on real-life issues and should be designed to encourage students to encounter unpredictable or inexplicable results.

Conclusions and didactic implications

A didactical implication is that chemistry education needs to include activities that allow students to encounter uncertainty. Activities based on chemistry content with inherent uncertainty

allows students' own considerations and complexity to unfold, which enhances students' participation and the connections to their everyday lives. This regards both sustainability issues (paper I) and chemistry content issues (paper II).

The models for complexity emphasise how important it is for students to experience the uncertainty and tentativeness which enhances both participation and complexity. Factual considerations are an essential part of chemistry education, but the models underline the importance of designing activities which afford other kinds of considerations. Therefore, these models can be a useful tool for teachers in the didactic analysis and design of chemistry education activities. The study also shows that the models are context related.

Students' own considerations contribute to the unfolding complexity. The factual considerations with sufficient facts (paper I) and the factual considerations (paper II) are related to traditional chemistry education, but are needed for disentangling the chemistry content knowledge. The factual considerations with insufficient facts, moral considerations (paper I) and exploratory considerations (paper II) are important to the complexity unfolding in the students' discussions. These considerations also present chemistry as tentative, and thereby encourage students to include their own knowledge, interests and ideas.

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Paper I

Cecilia Dudas är licentiand inom forskarskolan för didaktisk modellering (NaNo) vid Stockholms universitet samt förstelärare i kemi vid Globala gymnasiet i Stockholm.

Carl-Johan Rundgren är docent i naturvetenskapsämnenas didaktik vid institutionen för matematikämnets och naturvetenskapsämnenas didaktik (MND) vid Stockholms universitet. Han disputerade i naturvetenskapernas didaktik vid Linköpings universitet 2008 och hans forskning inriktar sig bl a på naturvetenskaplig medborgarbildning, särskilt i relation till media, och på användning av olika representationer av naturvetenskapliga fenomen.

Iann Lundegård är docent och lektor i naturvetenskapsämnenas didaktik vid Stockholms universitet. Hans forskningsintressen berör framförallt elevers samtal om miljö och hållbar utveckling i ett utbildningsinnehåll som befinner sig i skärningspunkten mellan natur och samhälle. Lundegård är också intresserad av pragmatisk utbildningsfilosofi och hans forskning bidrar till metodutveckling på det området.

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Didaktisk modellering av komplexa hållbarhetsfrågor i gymnasiets kemiundervisning

Abstract

To meet future challenges regarding sustainability issues, science education needs to address how to educate scientifically literate and responsible citizens. One aspect of this is how to draw students' attention to the complexity in sustainability issues. We explore how a didactic model and design principles can be developed and used to analyse complexity in students' deliberation on sustainability issues. The study has been conducted as an in-situ study at two upper secondary schools. The data was analyzed using Practical Epistemological Analysis (PEA) and Deliberative Educational Questions (DEQ). The results highlight four different kinds of considerations needed to visualize complexity, which were used to construct a didactic model. Those considerations regarded facts and values in relation to known and unknown facts. Design principles were also developed, which together with the model can support teachers in didactic analyses regarding complex sustainability issues in chemistry education. Furthermore, the study shows that chemistry education can contribute to development of Bildung and democratic citizenship.

Introduktion

Stockholm Resilience Center har identifierat nio planetära gränsvärden där mänsklig aktivitet hotar jordens möjligheter till självreglering (Rockström et al. 2009). Flera av dessa knyter an till kemiämnet: ozonlagrets uttunning; havsförsurning; biogeokemiska flöden (fosfor- och kvävecykler); aerosoler i atmosfären; nya kemiska substanser (t.ex. mikroplaster, organiska miljögifter och nanopartiklar). För att förstå och diskutera dessa och andra komplexa hållbarhetsfrågor med naturvetenskapligt innehåll behövs ämneskunskaper, men dessa kunskaper behöver också sättas i ett socialt sammanhang. En av gymnasieskolans utmaningar är således att utveckla en undervisning i naturvetenskapliga ämnen som erbjuder såväl kunskaper för vidare studier i naturvetenskap som medborgarbildning. Föreliggande studie syftar till att undersöka hur en undervisning som stöttar eleverna i att uppmärksamma komplexitet i kemiundervisningens hållbarhetsfrågor kan designas samt hur en sådan undervisning kan bidra till elevernas naturvetenskapliga medborgarbildning. Studien avser också att utveckla en didaktisk modell för analys av komplexitet i elevers resonemang runt dessa frågor.

Tidigare studier om hållbarhetsfrågor i kemiundervisning

Flertalet tidigare studier diskuterar hållbarhetsfrågor i kemiundervisningen. Dessa undersöker exempelvis undervisningssekvenser vid arbete med miljöfrågor i kemiundervisningen (t.ex. Marks, Bertram & Eilks 2008; Marks & Eilks, 2009; Marks & Eilks, 2010; Burmeister & Eilks, 2012). Elevers argumentation och beslutsfattande i debatter och samtal om hållbarhetsfrågor studeras också (t.ex. Christenson, Gericke & Chang Rundgren, 2017; Kolstø, 2006; Sadler & Zeidler, 2005). Andra artiklar har en mer teoretisk ingång och diskuterar olika modeller för arbete med hållbarhetsfrågor i kemiämnet (Burmeister, Rauch & Eilks, 2012). Flera artiklar diskuterar också kemiämnet i relation till bildningsperspektivet (t.ex. Sjöström, 2013) samt hur kritisk - reflexiv kemiundervisning kan möjliggöra kritiskt tänkande och aktivt medborgarskap (t.ex. Sjöström & Talanquer, 2014). Studier som analyserar hållbarhetsfrågor i kemiämnet saknas således inte, men frågan behöver undersökas vidare (Sjöström, Rauch och Eilks 2015). Rudsberg och Öhman (2010) uppmärksammar exempelvis att få studier har gjorts om hur arbetet med deltagande och pluralistiska arbetsformer i naturvetenskapliga ämnen tar sig uttryck i klassrummet.

Naturvetenskaplig medborgarbildning

Det finns flera olika traditioner som diskuterar utbildning för medborgarbildning. En av dessa är *Bildung*, som inbegriper både en process och ett sätt att vara (Wickman, Liberg & Östman, 2012). Ibland används begreppen *bildning* på svenska respektive *dannelse* på norska och danska som motsvarigheter till tyskans Bildung. Här väljer vi dock att använda den internationellt brukade termen Bildung. Bildung innefattar personlig och samhällelig utveckling samt solidaritet och ett ansvar att agera för att förändra samhället i en positiv riktning (Elmose & Roth, 2005; Wickman et al., 2012). Bildung handlar också om att utveckla både ett självständigt och kritiskt förhållningssätt till omvärlden. Relationen mellan självständighet och ansvarsfullt medborgarskap skapar en spänning mellan personliga och sociala värden (Sjöström, Frerichs, Zuin & Eilks, 2017). Traditionellt sett har dock inte naturvetenskapliga ämnen betonats som relevanta för utveckling av en persons Bildung (Sjöström et al., 2017; Wickman et al., 2012). Sjöström (2013) menar vidare att Bildungs-inriktad kemiundervisning kan bidra till naturvetenskaplig medborgarbildning.

Ett närliggande perspektiv är "education through science" (Holbrook, 2010) vars övergripande mål beskrivs som: *"The ultimate goal is that the education enables a person to function with society as a responsible citizen, able to incorporate science understanding into decision making activities and to appreciate the value of science in today's society"* (Holbrook, 2010, s. 87). Holbrooks utgångspunkt är att många länder har lärandemål som inte är direkt knutna till ett specifikt ämne, utan förväntas uppnås utifrån utbildningen som helhet. I arbetet mot dessa mål måste även de naturvetenskapliga ämnena delta. Holbrook menar vidare att om detta ska kunna ske, krävs ett paradigmskifte i hur naturvetenskaplig undervisning bedrivs och betraktas. För närvarande finns ett starkt fokus på äm-

nesinnehåll, vilket behöver ersättas med fokus på övergripande undervisningsmål. Detta innebär inte att naturvetenskapliga innehållet ska exkluderas, däremot behöver det omsättas i ett kulturellt och socialt sammanhang. Både Bildung och education through science betonar alltså betydelsen av att sätta naturvetenskapliga ämnen i ett socialt och kulturellt sammanhang för personlig och samhällelig utveckling samt för möjliggörande av ett ansvarsfullt medborgarskap.

Komplexa hållbarhetsfrågor i kemiundervisning

För att aktivt kunna delta i debatter och beslutsfattande rörande samhällsutmaningar och verka för en hållbar framtid är kunskaper i kemi viktiga (Chang Rundgren & Rundgren, 2015; Childs, Hayes & O'Dwyer, 2015; Eilks & Hofstein, 2015). Om utbildning i kemi ska vara relevant i förhållande till hållbar utveckling är det inte tillräckligt med ämneskunskaper, utan undervisningen måste organiseras så att eleverna får möjlighet att utveckla kompetenser för att förstå och delta i samtal där kunskaper i kemi behövs och efterfrågas (Burmeister et al., 2012; Sjöström et al., 2015). En översikt av undervisning i naturvetenskapliga ämnen i Israel, Tyskland och USA visade att möjligheten för eleverna att delta i diskussioner om hållbarhetsfrågor ofta saknades (Hofstein, Eilks & Bybee, 2011).

En metod att arbeta med hållbarhetsfrågor i naturvetenskaplig undervisning är att utgå från Socioscientific Issues (SSI), vilka har sin bas i naturvetenskapen men med potentiellt stor påverkan på samhället (t.ex. Sadler & Zeidler, 2005; Chang Rundgren & Rundgren, 2010). Frågor inom SSI är autentiska och aktuella (Ratcliffe & Grace, 2003) samt kontroversiella där olika aktörer har olika perspektiv, vilket också synliggörs genom den inneboende osäkerheten (Simonneaux, 2008). Frågor som är ostrukturerade, övergripande, svåra eller omöjliga att lösa på grund av ofullständiga, motsägelsefulla och föränderliga krav på kunskapsinnehåll benämns ibland "wicked problems" (Weber & Khademian, 2008). Kännetecknande för dessa är också att olika intressenter har motstridiga tolkningar av problemet och dess lösningar (Kreuter, De Rosa, Howze & Baldwin, 2004). Begreppet "wicked" ska här inte förstås som att frågorna är ondsinta, utan snarare i betydelsen mångfacetterade eller svårfångade. Undervisning utifrån SSI inkluderar att hantera problem och utmaningar som till sin natur är komplexa, ostrukturerade och öppna för diskussion (Simonneaux, 2008), vilket knyter an till beskrivningen av wicked problems. SSI och wicked problems kan förstås som frågor där det är svårt att reda ut fakta kring orsak och verkan, där det inte finns konsensus i identifiering av problem och lösningar samt att frågor genomsyras av olika värdemässiga perspektiv och intressekonflikter och att det inte finns en slutgiltig lösning. Flertalet tidigare studier visar att resonemang inom SSI inte bara handlar om ett naturvetenskapligt innehåll utan också om sociala perspektiv och värderingar (t.ex. Aikenhead, 1985; Simonneaux, 2008; Chang Rundgren och Rundgren, 2010). Komplexa naturvetenskapliga hållbarhetsfrågor har följaktligen både ett faktamässigt och ett värdemässigt innehåll.

Tidigare studier pekar på vikten av att eleverna ges möjlighet att uppmärksamma den komplexitet som föreligger i hållbarhetsfrågor (Simonneaux, 2008; Öhman, 2008; Öhman & Öhman, 2012). I föreliggande studie har vi valt att undersöka följande aspekter av komplexitet: att kunskaper i kemi efterfrågas för att förstå hållbarhetsfrågor och dess eventuella lösningar; att motstridiga perspektiv och värderingar förekommer samt att det finns en osäkerhet i kunskapsinnehållet vilket tillsammans med motstridiga perspektiv och värderingar gör frågan ofullständig, svårutredd och motsägelsefull.

Pluralism och demokratisk deliberation

I en pluralistisk undervisningstradition ses hållbarhetsfrågor som konflikter mellan olika värderingar, perspektiv och intressen (Öhman, 2008). I det sammanhanget kan skolan fungera som en arena där olikheter synliggörs och där elever deltar i demokratisk deliberation (Sandell, Öhman & Östman, 2003). Det deliberativa samtalet kan då bli ett sätt för eleverna att uppmärksamma olika sätt att förstå olika perspektiv och värderingar på frågorna (Lundegård & Wickman, 2007; Van Poeck & Vandenabeele, 2012). Här utgår undervisningen inte från något förbestämt rätt svar eller förhållningssätt

utan att var och en måste få tillfälle att argumentera för de val de gör (Rudsberg & Öhman, 2010). Ett mål med en pluralistisk undervisning är att stärka elevernas demokratiska handlingskompetens vilket kan ske genom att eleverna får tillfälle att uppmärksamma de konflikter och värderingar som finns inom aktuella hållbarhetsfrågor (Lundegård & Wickman, 2007; Öhman & Öhman, 2012). Sund (2015) menar vidare att komplexiteten i hållbarhetsfrågor i undervisningssammanhang ofta skalas bort, vilket kan vara till nackdel för elevernas möjlighet till att utvecklas som demokratiska medborgare. Rudsberg och Öhman (2010) menar att om en demokratisk process är att betrakta som situationer där elever kan skapa nya möjligheter genom att influera varandra, så kan pluralism ses som en av demokratins centrala beståndsdelar. I det sammanhanget kan utbildning kan således erbjuda ett forum där medborgarskap kan utvecklas (Van Poeck & Vandenabeele, 2012). Genom möten med andra, får eleverna tillfälle att diskutera och ta ställning i hållbarhetsfrågor där de ges möjligheter att skapa nya sätt att agera och vara (Lundegård & Wickman, 2012; Van Poeck & Vandenabeele, 2012).

I föreliggande studie inspireras undervisningen innehållsmässigt av SSI. Detta genom att den utgår från frågor i samhället där kunskaper i kemi efterfrågas. Det praktiska genomförande av undervisningen tar avstamp i en pluralistisk undervisningstradition i vilken möjligheten till deliberation är central vilket också synliggör hållbarhetsfrågornas komplexa aspekter.

Lärares perspektiv på undervisning utifrån hållbarhetsfrågor

Diskussioner med inslag av etiska och moraliska frågor har traditionellt sett inte varit en del av undervisningstraditionen i naturvetenskapliga ämnen (Roberts, 2007). Lärare uttrycker ofta att undervisning i naturvetenskap handlar om att eleverna ska lära sig fakta samt att undervisningen ska vara värderingsfri (Simonneaux, 2008). Enligt en studie av Borg, Gericke, Höglund & Bergman (2012) känner sig lärarna i de naturvetenskapliga ämnen säkra på att arbeta med hållbarhetsfrågor så länge dessa fokuserar på fakta, men mindre säkra när det kommer till att inkludera lärande för hållbar utveckling utifrån ett pluralistiskt perspektiv. Svårigheter att integrera hållbarhetsfrågor i undervisningen, avsaknad av inspirerande exempel, relevans i relation till ämnet samt brist på nya metoder, kunskap, stöttning och tid lyfts som hindrande faktorer (Rudsberg & Öhman, 2010; Borg et al., 2012; Ekborg, Ottander, Silver & Simon, 2013).

Metodologi

Ett pragmatiskt perspektiv på lärande

Studien tar avstamp i ett pragmatiskt perspektiv på lärande, inspirerat av Deweys teorier om lärande och Wittgensteins senare verk. Ett pragmatiskt perspektiv på lärande och meningsskapande innebär att lärandet ses som situerat och något som sker i ett socialt sammanhang. För att lära sig något nytt utgår människor från det de redan vet och de tidigare erfarenheter som är relevanta för den aktivitet som pågår (Wickman, 2013). Dewey (1925/1995) menar att kommunikation ger möjlighet till omprövning och revidering av vanor utifrån aktivitetens syfte och ur detta växer ett meningsskapande. Samspelet med omgivningen är då centralt för transformation av erfarenheter.

Design based research

Det praktiska genomförandet av studien är inspirerat av Design Based Research (DBR). DBR är en praktiknära forskningsmetod som syftar till att utveckla utbytet mellan forskningen och skolpraktiken (McKenney & Reeves, 2014; Andersson & Shattuck, 2012). I DBR är både forskare och lärare aktiva i att producera meningsfulla förändringar i undervisningen (McKenney & Reeves, 2014; The Design based research collective, 2003). En designstudie innebär att en intervention planeras och genomförs i flera cykler. Med en cykel menas här att undervisning, utifrån tentativa designprinciper, planeras, genomförs och analyseras. Analysen ligger sedan till grund för revidering av design-

principerna. Mellan varje cykel genomförs således förändringar som syftar till att utveckla och förfina designprinciper till nästa cykel (The design based research collective, 2003). Genom att arbeta med att utveckla designprinciper i samarbete med undervisande lärare kan undervisning och ny kunskap utvecklas. DBR syftar alltså till att vara både praktik- och teorigenererande (McKenney & Reeves, 2014).

De tentativa designprinciper som formulerades inför föreliggande studie var att elevernas aktivitet skulle innefatta demokratisk deliberation för att synliggöra motstridiga perspektiv och värderingar samt att innehållet skulle väljas så att kunskaper i kemi efterfrågas i dessa resonemang. Dessa formulerades utifrån lärarnas erfarenheter samt den tidigare forskning och lärandeteori som presenterats ovan.

Didaktisk modellering

Designstudien genomförs som en del av en didaktisk modellering (se artikel av Wickman, Lundegård & Hamza i detta nummer). Didaktisk modellering innebär här att undervisning planeras, genomförs och analyseras i cykler med syfte att utveckla en didaktisk modell. Wickman (2014) menar att en didaktisk modell bygger på hur didaktisk teori samspelar med praktik och syftar till att användas av lärare vid didaktisk analys för planering, genomförande och utvärdering av undervisning. Wickman menar vidare att detta innebär att didaktiska modeller måste utvecklas och modifieras i samverkan med lärare.

Metodologiskt finns flera beröringspunkter mellan didaktisk modellering och designstudier, exempelvis det nära samarbetet mellan praktik och teori samt att varken designstudier eller didaktisk modellering syftar till att skapa slutgiltiga modeller utan modeller som ständigt kan revideras och förfinas (The design based research collective, 2003; Wickman, 2014). En skillnad mellan DBR och didaktisk modellering är dock det förväntade kunskapsbidraget. Didaktisk modellering syftar till att utveckla en didaktisk modell medan en designstudie syftar till att utveckla designprinciper. I föreliggande studie utvecklas således både en didaktisk modell och designprinciper. Dessa kan komplettera varandra genom att den didaktiska modellen är mer övergripande och designprinciperna kan precisera användning av den.

Syfte och forskningsfrågor

Studien avser att utveckla en didaktisk modell som syftar till att analysera komplexitet i elevers deliberation om kemiundervisningens hållbarhetsfrågor. Studien syftar också till att undersöka hur undervisning kan designas för att stötta eleverna i att uppmärksamma den komplexitet som föreligger i dessa frågor samt hur denna undervisning kan bidra till naturvetenskaplig medborgarbildning.

Syftet konkretiseras i följande frågeställningar:

1. Vilka överväganden kan urskiljas när eleverna får möjlighet att delta i demokratisk deliberation om hållbarhetsfrågor i kemiundervisning?
2. Hur kan en didaktisk modell med syfte att analysera komplexitet i elevers deliberation utarbetas utifrån dessa överväganden?
3. Hur kan kemiundervisning designas för att stötta elever i att uppmärksamma komplexitet i hållbarhetsfrågor?

Genomförande

Studien genomfördes iterativt i två cykler i ett nära samarbete mellan undervisande lärare och forskare, såväl vid planering som genomförande. Trots de stora skillnader som finns mellan cyklerna har vi valt att benämna interventionerna som cykel 1 respektive cykel 2. Anledningen till detta är att planeringen och genomförandet av cykel 2 utgick från analysen av cykel 1. Då vi erfor att ämnesinnehållet och undervisningsmetoderna i cykel 1 inte stöttade eleverna i att uppmärksamma komplexiteten valde vi att förändra såväl innehållet som formen till nästa cykel. Nedan beskrivs hur de tentativa och reviderade designprinciperna konkretiserats i respektive cykel.

Cykel 1

Datainsamling

Cykel 1 genomfördes tillsammans med två kemilärare på en kommunal gymnasieskola i Stockholm med elever på Naturvetenskapliga programmet i årskurs 1, inom kursen kemi 1. Studien genomfördes i två klasser med sammanlagt 60 elever. Elevsamtal mellan elever i en av klasserna spelades in med video. Tre elevgrupper med tre till fem elever i varje grupp spelades in, totalt ingick 12 elever. Samtalen varade i ca 30 minuter.

Undervisningens genomförande

Inledningsvis arbetade eleverna med teori om elektrokemi. Därefter introducerades ett grupparbete där eleverna undersökte ett av sex givna batterityper. Arbetet redovisades på en poster. Därefter följde den inspelade lektionen som planerades utifrån de tentativa designprinciperna (se s. 271). Syftet med lektionen var att eleverna skulle använda sina kunskaper i kemi för att diskutera och ta ställning i hållbarhetsfrågor rörande batterier. Vid den inspelade lektionen hade eleverna möjlighet att söka information i kemiboken och på internet samt rådfråga andra elever eller läraren. Grupperna var sammansatta så att varje grupp innehöll elever som tidigare arbetat med olika batterier. Varje grupp blev tilldelade en av följande diskussionsuppgifter:

- Välj batteri till "smarta glasögon", diskutera för och nackdelar med de batterier ni arbetat med i de olika grupperna samt välj och motivera vilket batteri som du tycker är mest lämpligt.
- Välj batteri till "smart träningströja", diskutera för och nackdelar med de batterier ni arbetat med i de olika grupperna samt välj och motivera vilket batteri som du tycker är mest lämpligt.
- Välj batteri till "rymdraketen", diskutera för och nackdelar med de batterier ni arbetat med i de olika grupperna samt välj och motivera vilket batteri som du tycker är mest lämpligt.

Cykel 2

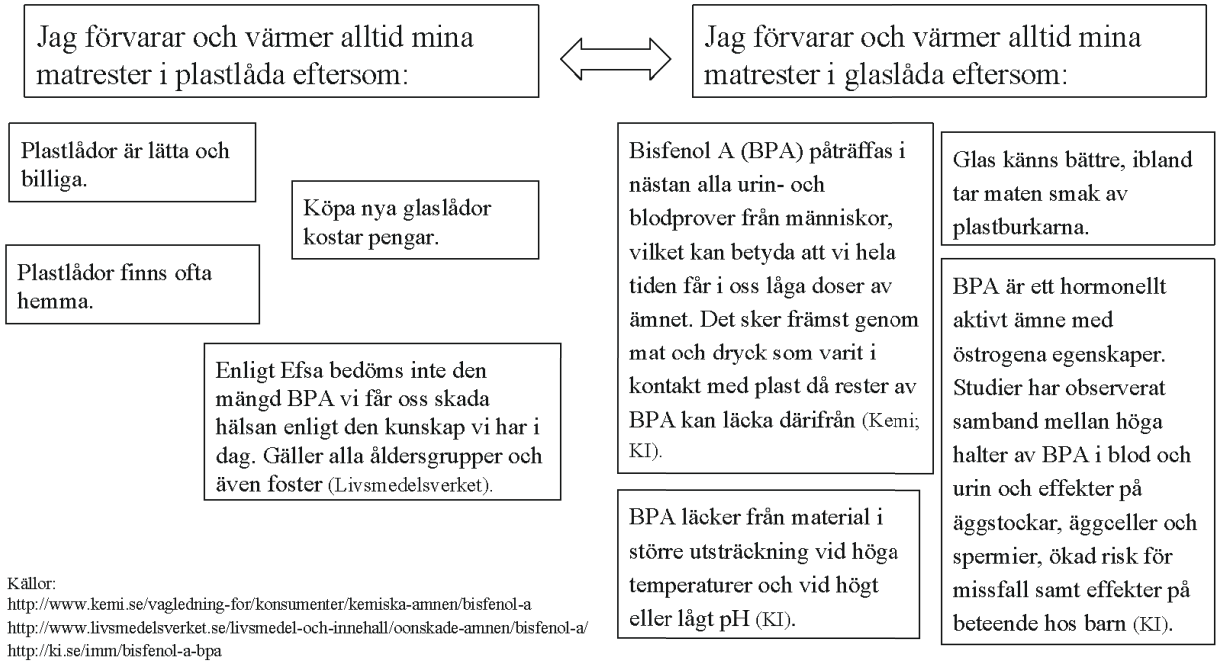
Datainsamling

Cykel 2 genomfördes tillsammans med tre kemilärare på två kommunala gymnasieskolor i Stockholm. Vid studiens genomförande var förstaförfattaren kemilärare på en av skolorna. Eleverna deltog i kursen kemi 2, i årskurs två (60 elever) respektive årskurs tre (51 elever) på Naturvetenskapliga programmet. Samtal med elva grupper, om tre till fyra elever, spelades in med video. Totalt deltog 38 elever. Samtalen varade 30–60 minuter. Eleverna i årskurs två deltog även i cykel 1. Cykel 2 genomfördes ca sex månader efter cykel 1.

Undervisningens genomförande

Inledningsvis arbetade eleverna med ett förberedande undervisningsmoment där teoriundervisning om miljökemi och miljögifter varvades med arbete i grupp. I grupperna valde eleverna en vardagsprodukt innehållandes ett organiskt miljögift som de undersökte. Därefter följde den inspelade lektionen som planerades utifrån de reviderade designprinciperna (se s. 278). För att stötta eleverna i att uppmärksamma osäkerhet valdes ett innehåll i forskningens framkant. Eleverna formulerade egna motsatta påståenden med argument för de båda "sidorna" för att synliggöra motstridiga perspektiv och värderingar. Syfte med lektionen var att eleverna skulle använda sina kunskaper i kemi för att diskutera och ta ställning i frågor rörande organiska miljögifter i vardagsprodukter samt att eleverna

skulle uppmärksamma olika perspektiv och tänkbara konflikter i dessa frågorna. Vid den inspelade lektionen hade eleverna möjlighet att söka information i kemiboken och på internet samt rådfråga andra elever eller läraren. Grupperna var sammansatta så att varje grupp innehöll elever som tidigare arbetat med olika produkter och miljögifter. Lektionen inleddes med att läraren visade och diskuterade följande exempel med eleverna:



Figur. 1. Introduktion till elevernas aktivitet i cykel 2

Därefter fick grupperna följande instruktioner:

- Redogör kort för innehållet i era respektive rapporter/tidigare diskussioner.
- Formulera ett dilemma (motsatta påståenden) som rör hur man kan resonera runt en vardagsprodukt innehållandes ett organiskt miljögift.
- Hitta argument som stödjer eller motsäger era påståenden. Anteckna på post-it lappar. En färg för varje "sida", placera dessa under respektive påstående på ett A3-papper.
- Vad tycker du? Motivera och diskutera era egna ställningstaganden i frågan.

Exempel på dilemma grupperna formulerade och diskuterade var: "*Poppa popcorn i mikro - poppa popcorn i kastrull", "Leksaker av plast - leksaker av andra material ", "Använda kläder med Gore-Tex - använda kläder utan Gore-Tex", "Släcka bränder med brandskum innehållandes perfluorerade ämnen - släcka bränder med vatten", "Välja tandkräm med triclosan - välja tandkräm utan triclosan".*

Analys

Det inspelade materialet transkriberades i sin helhet. För att analysera materialet och följa elevernas meningsskapande har Praktisk Epistemologisk Analys och Deliberative Educational Questions använts som analysverktyg. Dessa presenteras närmare nedan.

Praktisk Epistemologisk Analys och Deliberative Educational Questions

Den kvalitativa analysen tar avstamp i en didaktisk modell för analyser av klassrumssamtal, Deliberative Educational Questions (DEQ) (Lundegård & Wickman, 2007), som baseras på Praktisk Epistemologisk Analys (PEA) (Wickman & Östman, 2002; Wickman, 2004). PEA har utvecklats som en metod för att analysera lärande och meningsskapande och bygger på ett pragmatiskt perspektiv på lärande. PEA utgår från fem begrepp; syfte, stå fast, mellanrum, relation, möte (Wickman & Östman, 2002). Dessa begrepp handlar om hur elever i *möten* med varandra och omgivningen använder språk och andra handlingar för att foga samman tidigare erfarenheter med nya sätt att göra och tala om saker. Alla kommunikativa möten utgår från att något *står fast* mellan de som ingår i en situation, annars skulle kommunikationen inte upprätthållas. När nya *mellanrum* uppstår mellan de samtalande och dessa fylls med *relationer*, så transformeras den erfarenhet som behövs för att komma vidare (Wickman, 2013). Vid PEA är det dock inte de individuella elevernas uttalande och handlande som är intressanta att analysera utan hur innehållet skapas genom de transaktioner som utgör processen (Lundegård & Wickman, 2007).

DEQ är en didaktisk modell som används för att synliggöra de överväganden som elever möter i sin diskussion om hållbarhetsfrågor (Lundegård & Wickman, 2007; 2012). I den ena individens uttalande finns det ofta en valmöjlighet inbyggd, för den andre att ta ställning till genom att antingen ifrågasätta eller acceptera påståendet. Dessa pågående valmöjligheter påverkar sålunda vilken riktning samtalet tar och vilket meningsskapande som utvecklas. I det ständiga utbytet av kommunikativa handlingar tvingas eleverna kliva fram på arenan och blotta sig i sina fortgående ställningstaganden, *"I am forced to either connect with one of the distinctions (s)he has made, or to create my own new distinction"* (Lundegård & Wickman, 2012, s. 165). Analysmetoden innebär att omformulera de mellanrum som uppmärksammas i elevers samtal till deliberativa frågor. Mellanrummet är svaret på den fråga som (implicit) besvaras genom att det knyts en relation mellan elevernas yttranden. Dessa överväganden kan förstås som de val eleverna gör då de ges möjlighet att uppmärksamma olika värderingar och intressekonflikter (Lundegård & Wickman, 2007).

I denna studie görs en distinktion mellan DEQ som innebär överväganden med ett mer faktamässigt innehåll och överväganden med ett mer värdemässigt innehåll. Vi ser dock dessa kategorier som delvis överlappande. Ofta är det problematiskt att skilja fakta från värdeomdömen (Lundegård & Wickman, 2007; Wickman, 2013). Wickman (2004) menar att inlärningen av fakta alltid ackompanjeras av värderingar, om inte annat i termer av att eleverna lär sig om de gillar det de håller på med eller inte. I denna studie ser vi det som att samtalet i sin helhet har ett värderande syfte och mål men att vissa val på vägen har ett faktamässigt innehåll.

I excerpten nedan visas ett exempel på hur DEQ analysen genomförts. Syftet med samtalet är att diskutera och jämföra mikropopcorn respektive kastrullpopcorn. I sekvensen diskuterar eleverna förekomsten av perfluorerade ämnen i mikropopcorn.

1. Elin: vad har det för effekter på…?
2. Frida: det kan vara hormonstörande.
   (Mellanrum uppmärksammas: är effekten hormonstörande?)
3. Elin: men också om man tänker på att det är barn igen som konsumerar mest…
4. Jonas: mmm
   (Mellanrum uppmärksammas: är det relevant att barn har en högre konsumtion?)
5. Elin: …dom är ju känsligare.
6. Frida: just det.
   (Mellanrum uppmärksammas: är barn känsligare?)

Ur det korta meningsutbytet kan tre DEQ urskiljas ur de mellanrum som uppmärksammades i transaktionen mellan eleverna.

1: Är en effekt av perfluorerade ämnen att det är hormonstörande eller inte?
2: Bör hänsyn tas till barnens högre konsumtion av popcorn eller inte?
3: Är barn känsligare för påverkan än vuxna eller inte?

DEQ 1 och 3 betraktas här som med ett framförallt faktamässigt innehåll medan DEQ 2 har ett mer värdemässigt innehåll.

I föreliggande studie genomfördes analysen i två steg som båda utgick från de DEQ som urskilts i elevernas samtal. Det första steget i analysen syftade till att utveckla den didaktiska designen av undervisningen (forskningsfråga 3). Först analyserades de DEQ som urskildes i cykel 1 utifrån de olika aspekterna av komplexitet som formulerats i studien. Utifrån analysen reviderades designprinciperna inför cykel 2. Efter genomförandet av cykel 2 analyserades de DEQ som urskildes där.

Det andra steget syftade till att utarbeta en didaktisk modell (forskningsfrågorna 1 och 2). Denna analys utfördes efter att de båda cyklerna var genomförda. Samtliga DEQ analyserades då för att undersöka om några kategorier av överväganden som synliggör komplexitet kunde utkristalliseras. Utifrån de kategorier som uppkom utarbetades den didaktiska modellen (tabell 1). Slutligen användes den didaktiska modellen för att kvantitativt analysera DEQ i cykel 1 respektive 2 (tabell 3).

Resultat

Vilka överväganden kan urskiljas när eleverna får möjlighet att delta i demokratisk deliberation om hållbarhetsfrågor i kemiundervisning?

För att besvara forskningsfråga 1 analyserades och kategoriserades de DEQ som uppkommer i de båda cyklerna. De mönster som utkristalliserades beskrivs efter excerpten.

Nedan visas ett samtal mellan tre elever i cykel 2 som syftar till att diskutera dilemmat *"leksaker till barn i plast - leksaker i andra material"* som de själva har formulerat. Excerpten har valts då de är exempel på samtal där karakteristiska DEQ går att identifiera i cykel 2. De används här för att exemplifiera och tydliggöra hur olika typer av överväganden kan ta sig uttryck. Tidigare i samtalet har eleverna uppmärksammat att leksaker i plast kan innehålla ftalater. Nedan använder eleverna inte begreppet ftalater utan istället "det", "såna grejer", "miljögifterna" samt "ämnet".

1. Adele: ni som jobbade med plast, fick ni fram något om argument *det* är skadligt för hälsan?
2. Kim: alltså man vet ju inte säkert, fortfarande…men att man inte vet är ju snarare orsak att låta bli, att vara försiktig, försiktighetsprincipen. Vi kan ju komma på några…
3. Adele: motargument?
4. Kim: Ja, öhhh … det är osäkert och det är risk för exponering, eller det är ju en exponering.
5. Anna: det beror väl på om det är *såna grejer* i plasten
6. Kim: jo, precis.
   DEQ 1: Är ftalater skadligt för hälsan eller vet forskarna inte säkert?
   DEQ 2: Bör vi chansa på att det inte är farligt eller resonera utifrån försiktighetsprincipen, när vi inte vet säkert?
   DEQ 3: Blir vi alltid exponerade om det finns "såna grejer" i plasten eller inte?
   […]
7. Kim: men om man gör sig av med alla plastleksaker, måste man ju ersätta dom på något sätt
8. Emilie: det är inte ekonomiskt hållbart
9. Anna: men jag tänker också, kommer *miljögifterna* minska om man så här återvinner leksakerna? Om dom har gått flera generationer.
10. Kim: att dom redan gett ifrån sig liksom…? Kanske?
11. Anna: är det någon skillnad?

12. Kim: men om det är så här, eller det finns ju en begränsad mängd av *ämnet* liksom i ytskiktet av leksaken, så så småningom borde det väl… men jag vet inte under hur lång period den kan fortsätta släppa ifrån sig.
13. Anna: och hur ser leksaken ut när alla…
14. Kim: ja, precis. Den bryts långsamt ner och blir hårdare och hårdare…och till slut har den släppt ut alla…Ja.
    DEQ 4: Bör plastleksaker ersättas med andra leksaker eller blir det inte ekonomiskt hållbart?
    DEQ 5: Läcker ftalater ut över tid eller är koncentrationen i ytskiktet konstant?
    DEQ 6: Kommer det märkas någon skillnad på materialet när ftalaterna läckt ut eller kommer det vara likadant?

En analys av elevernas meningsutbyte visar att deras överväganden rör sig på flera olika nivåer. Ibland har de ett faktamässigt innehåll där faktakunskap finns tillgänglig (DEQ 3, DEQ 5, DEQ 6). Andra gånger efterfrågas faktakunskaper som inte ännu finns att tillgå på området (DEQ 1). Vad gäller elevernas värdemässiga överväganden är dessa ibland sådana att faktakunskaper tillsammans med andra erfarenheter och värderingar kan vägleda eleverna i deras ställningstaganden (DEQ 4) men ibland stöter eleverna på värdemässiga frågor där fakta saknas (DEQ 2).

Hur kan en didaktisk modell med syfte att analysera komplexitet i elevers resonemang utarbetas utifrån dessa överväganden?

Vid analysen av samtliga DEQ utkristalliserades fyra olika typer av överväganden enligt ovan. Dessa kategorier användes för att utarbeta den didaktiska modellen nedan (tabell 1). Samtliga DEQ som urskildes i elevernas samtal kunde kategoriseras enligt den didaktiska modellen.

Tabell 1. Didaktisk modell för analys av komplexitet i deliberation om hållbarhetsfrågor.

Faktamässiga överväganden Faktakunskaper efterfrågas för att hantera övervägandet.	
- med tillräcklig faktakunskap (DEQ 3, 5, 6) Faktakunskap finns att tillgå.	**- med otillräcklig faktakunskap** (DEQ 1) Faktakunskap finns (ännu) inte att tillgå varken bland eleverna, lärare eller forskningssamhället.
Värdemässiga överväganden Faktakunskaper, värderingar och andra erfarenheter efterfrågas för att hantera övervägandet. Elevernas ställningstaganden kan bli olika beroende på deras värderingar och erfarenheter.	
- med tillräcklig faktakunskap (DEQ 4) Faktakunskap finns att tillgå.	**- med otillräcklig faktakunskap** (DEQ 2) Faktakunskap finns (ännu) inte att tillgå.

I föreliggande studie undersöks olika aspekter av komplexitet i elevers deliberation. En av dessa aspekter är att kemi efterfrågas, vilket i modellen ovan kan synliggöras i faktamässiga överväganden. En annan aspekt är att motstridiga perspektiv och värderingar uppmärksammas, vilket i modellen synliggörs i värdemässiga överväganden. Ytterligare en aspekt är frågornas ofullständighet och osäkerhet, vilket i modellen framförallt synliggörs i överväganden med otillräcklig faktakunskap. För att synliggöra komplexitet berörs alltså faktamässiga och värdemässiga överväganden, med både tillräcklig och otillräcklig faktakunskap. Överväganden i samtliga fyra kategorier behövs följaktligen för att synliggöra komplexitet i kemiundervisningens hållbarhetsfrågor.

Vi vill här betona att värdemässiga och faktamässiga överväganden kan vara överlappande samt att faktakunskap inte är antingen tillräcklig eller otillräcklig utan att dessa kategorier är delar av ett kontinuum.

I tabell 2 visas exempel på hur dessa olika typer av överväganden kan ta sig uttryck i elevers deliberation.

Tabell 2. Exempel på överväganden från cykel 1 respektive cykel 2.

Faktamässiga överväganden	
- med tillräcklig faktakunskap	**- med otillräcklig faktakunskap**
Cykel 1 *Är det skillnad på alkaliska laddningsbara och engångsbatterier eller inte?* *Är alkaliska eller Li-I batterier starkare?*	Cykel 1 *Kan vi minska mängden alger eller kan det finnas ett syfte med att det finns mycket alger som vi inte känner till?* *Kommer algbatteriet kunna uppfylla alla de krav vi har satt upp eller inte?*
Cykel 2 *Finns ftalater i alla mjukplaster eller bara i vissa?* *Lagras högfluorerade ämnen i fettvävnad eller lagras de inte alls?*	Cykel 2 *Innehåller mikropopcorn tillräckligt höga halter av PFOA för att kunna påverka eller är dosen för liten?* *Är ftalater skadligt för hälsan eller vet inte forskarna säkert?*
Värdemässiga överväganden	
- med tillräcklig faktakunskap	**- med otillräcklig faktakunskap**
Cykel 1 *Är alkaliska eller Li-I batteri det bästa alternativet i dagsläget?* *Har alkaliska eller Li-I batterier har mest nackdelar?*	Cykel 1 *Är det värt risken med algbatteriet eller är det bättre att fortsätta använda de gamla mindre miljövänliga batterierna?* *Kommer skördandet av alger ske försiktigt eller finns det en risk att någon tar för mycket om man kan tjäna pengar på det?*
Cykel 2 *Vilka fördelar finns med mikropopcorn jämfört med kastrullpopcorn?* *Skulle det vara jobbigt att segla eller vara ute i naturen utan Gore-Tex kläder eller inte?*	Cykel 2 *Bör vi ta hänsyn till cocktaileffekten när vi pratar om doser eller inte?* *Tycker du att miljögifter fyller en viktig funktion i någon av de produkter som vi har diskuterat som motiverar fortsatt användning av dom eller bör vi sluta använda dem?*

Hur kan kemiundervisning designas för att stötta elever i att uppmärksamma komplexitet i hållbarhetsfrågor?

Nedan beskrivs i vilken utsträckning de olika aspekterna av komplexitet uppmärksammades av eleverna samt hur designen reviderades till cykel 2.

Cykel 1

Vad gäller motstridiga perspektiv och värderingar synliggjordes dessa inte i elevernas överväganden med tillräcklig faktakunskap, utan här var eleverna överens om hur fakta ska värderas. Eleverna resonerade som att det går att hitta ett batteri som är energirikt, miljövänligt, billigt och litet. Ingen elev reflekterade heller över om produkterna behövs. Att frågan kan ses ur olika perspektiv och att olika intressenter kan ha olika tolkningar av problemet och dess lösningar berördes i större utsträckning i värdemässiga överväganden med otillräcklig faktakunskap. Dessa förekom dock i liten utsträckning i cykel 1 och då endast i relation till algbatteriet.

Eleverna i cykel 1 efterfrågade i stor utsträckning kunskaper i kemi. Dessa överväganden handlade framförallt om olika batteriers egenskaper samt om jämförelser mellan olika batterier.

I cykel 1 formulerades endast sju (se tabell 3) överväganden som synliggjorde osäkerhet och ofullständighet, och då enbart i resonemang runt algbatteriet.

Revidering av designprinciper inför cykel 2

Då analysen av cykel 1 visade att eleverna i låg utsträckning uppmärksammade komplexitet reviderades designprinciperna till cykel 2.

I cykel 2 undersöktes om motstridiga perspektiv och värderingar tydligare kunde uppmärksammas genom att elevernas aktivitet explicit efterfrågar detta. Aktiviteten designades därför så att eleverna skulle formulera dilemman om en vardagsprodukt innehållandes organiska miljögifter *(exempelvis: jag äter alltid mikropopcorn - jag äter alltid kastrullpopcorn*) med för- och motargument för de båda ställningstagandena (se s. 272-273).

I cykel 1 synliggjordes frågans ofullständighet och brist på lösningar endast i förhållande till algbatteriet där elever, lärare och forskare har otillräcklig faktakunskap. I cykel 2 undersöktes därför om eleverna tydligare kunde uppmärksamma osäkerhet att när aktiviteten tar avstamp i frågor i forskningens framkant. Utifrån detta bestämdes att cykel 2 skulle handla om organiska miljögifter i vardagsprodukter.

De reviderade principerna för designen i cykel 2 var således dels att explicit efterfråga motstridiga perspektiv och värderingar samt dels att utgå från frågor i forskningens framkant. Att välja ett innehåll så att kunskaper i kemi efterfrågas i elevernas resonemang kvarstår som designprincip.

Cykel 2

Även i cykel 2 var det framförallt i värdemässiga överväganden med otillräcklig faktakunskap som eleverna diskuterade olika perspektiv, konflikter mellan dessa och tog ställning. De ifrågasatte explicit behovet av en del av produkterna och användningen av miljögifter i dessa: *Ska vi utgå från försiktighetsprincipen när det gäller produkter som inte är livsnödvändiga eller ska vi använda dom ändå?*

I cykel 2 efterfrågades kunskaper i kemi i stor utsträckning. Dessa överväganden handlade framförallt om förekomst av miljögifter i olika produkter, vad som händer med miljögiftet i kroppen, om miljögiftets egenskaper, om vilka doser som är skadliga, exponering samt om vad som är "bevisat".

Eleverna i cykel 2 uppmärksammade ofullständighet och osäkerhet i stor utsträckning. Detta visade sig dels som överväganden som explicit pekar på osäkerhet: *Kan forskning bevisa samband mellan ftalater och astma/allergier eller är forskarna oense?* samt dels som överväganden om risk och försiktighet: *Är det ok att exponeras för ftalater eftersom vi inte vet om alla är hormonstörande eller är det en onödig risk att ta?*

Kvantitativ sammanställning av överväganden i cykel 1 respektive cykel 2

En kvantitativ sammanställning (tabell 3) visar att de DEQ som uppkom i cykel 1 framförallt handlade om överväganden med tillräcklig faktakunskap, både med faktamässigt och värdemässigt innehåll. I cykel 2 syntes en jämnare fördelning av överväganden mellan de fyra kategorierna, vilket innebär att andelen värdemässiga överväganden respektive överväganden med otillräcklig faktakunskap ökade i cykel 2. Genom den nya designen i cykel 2 stöttades eleverna i att uppmärksamma komplexiteten i större utsträckning.

Tabell 3. Kvantitativ sammanställning av överväganden i cykel 1 respektive 2.

Faktamässiga överväganden	
- med tillräcklig faktakunskap	**- med otillräcklig faktakunskap**
Cykel 1: 78 st.	Cykel 1: 3 st.
Cykel 2: 160 st.	Cykel 2: 65 st.
Värdemässiga överväganden	
- med tillräcklig faktakunskap	**- med otillräcklig faktakunskap**
Cykel 1: 30 st.	Cykel 1: 4 st.
Cykel 2: 73 st.	Cykel 2: 80 st.

I den första cykeln formulerades 115 DEQ och i den andra 378 DEQ. Skillnaden kan förklaras med att det inspelade materialet var mer omfattande i cykel 2 (se s. 272).

Sammanfattning av resultat

I studien utkristalliserades fyra olika typer av överväganden. Dessa överväganden rör fakta och värderingar i relation till tillräcklig respektive otillräcklig faktakunskap. Utifrån dessa överväganden utarbetades en didaktisk modell som syftar till att analysera komplexitet i elevers resonemang.

I studien utvecklades också tre designprinciper:

- att explicit efterfråga motstridiga perspektiv och värderingar.
- att välja ett innehåll så att kunskaper i kemi efterfrågas i elevernas resonemang.
- att utgå från frågor i forskningens framkant.

Diskussion

De två första frågeställningarna handlar om vilka sorts överväganden som elever möter i deliberation om hållbarhetsfrågor samt hur en didaktisk modell för analys av komplexitet i elevers resonemang kan utarbetas utifrån dessa överväganden.

Den naturvetenskapliga undervisningstraditionen har haft ett stort fokus på fakta (Holbrook, 2010; Simonneaux, 2008) och i hållbarhetsfrågor hyser lärare i naturvetenskapliga ämnen ofta en förhoppning om att eleverna ska resonera utifrån relevanta faktakunskaper (Chang Rundgren & Rundgren, 2010). I föreliggande studie förekommer faktamässiga överväganden i stor utsträckning, vilket tyder på att eleverna efterfrågar kunskaper i kemi för att ta sig vidare i aktiviteten. Således erbjuder aktiviteterna eleverna möjlighet att delta i samtal där kemi behövs och efterfrågas, vilket är viktigt för att ämnet ska vara relevant i förhållande till hållbar utveckling (Burmeister et al., 2012; Sjöström et al., 2015). Men för att bidra till utveckling av ansvarsfulla medborgare behöver ämneskunskaper också sättas i ett socialt sammanhang (Holbrook 2010).

Vad gäller värdemässiga överväganden visar tidigare studier (t.ex. Sandell et al., 2003; Van Poeck och Vandenabeele, 2012) på vikten av att skolan erbjuder en arena där eleverna får möta motstridiga perspektiv och värderingar. Detta stärker elevernas demokratiska kompetens (Lundegård & Wickman, 2007). Flera studier pekar också på vikten av att undervisningen explicit synliggör konflikter mellan motstridiga perspektiv och värderingar för att uppmärksamma den komplexitet som finns i hållbarhetsfrågor (Öhman, 2008; Öhman & Öhman, 2012) och att det ur ett demokratiskt perspektiv är viktigt att komplexiteten inte skalas bort (Sund, 2015). I föreliggande studie synliggörs motstridiga perspektiv och värderingar framförallt i kategorin värdemässiga överväganden med otillräcklig faktakunskap. I cykel 2 handlar dessa i stor utsträckning om sammanhang där eleverna resonerar om försiktighetsprincipen och cocktaileffekten samt om hur de ska förhålla sig till hållbarhetsfrågor då faktakunskap inte finns att tillgå. Här erbjuds möjlighet för eleverna att erfara olika perspektiv och värderingar samt att ta ställning (Lundegård & Wickman 2007; Van Poeck och Vandenabeele, 2012). Tidigare studier har också visat att elever ofta använder personlig erfarenhet och värderingar när det inte finns tydliga fakta att tillgå (Chang Rundgren & Rundgren, 2010). Både föreliggande studie och tidigare forskning pekar följaktligen på vikten av att både faktamässiga och värdemässiga överväganden uppmärksammas i den naturvetenskapliga undervisningen.

Föreliggande studie visar att överväganden med otillräcklig faktakunskap ofta berör frågor i forskningens framkant där det finns en osäkerhet eller otillräcklighet i kunskapsinnehållet. Inom den pluralistiska undervisningstraditionen ses osäkerhet inom hållbarhetsfrågor som en viktig beståndsdel, där naturvetenskap inte kan visa den "rätta" vägen att handla (Sund, 2015). I frågor som saknar enkla lösningar måste var och en måste argumentera för de val som görs (Rudsberg & Öhman, 2010). Att ställas inför överväganden där det inte finns några svar är viktigt för att synliggöra frågans komplexitet (Simonneaux, 2008). Både frågor inom SSI och wicked problems handlar om att möta och diskutera samhällsutmaningar som är komplexa, kontroversiella och med stor grad av osäkerhet (Simonneaux, 2008) samt svåra att lösa på grund av ofullständiga, motsägelsefulla och föränderliga krav på kunskapsinnehåll (Weber & Khademian, 2008). Studien visar att denna osäkerhet och förändlighet i stor utsträckning berörs av eleverna i cykel 2, exempelvis när Kim (s. 275) säger: *alltså man vet ju inte säkert, fortfarande… men att man inte vet är ju snarare orsak att låta bli, att vara försiktig, försiktighetsprincipen.*

Bildung innebär både att utvecklas som individ i samhället samt att utveckla ett ansvarsfullt förhållningssätt i relation till samhället (Sjöström et al., 2017; Wickman et al., 2012). I föreliggande studie diskuterar eleverna personliga och samhälleliga aspekter av vilka följder deras val kan få för dem själva och andra, nu och i framtiden. Här får de användning av både faktamässiga och värdemässiga kunskaper. Studien pekar alltså på att kemiundervisning kan vara både relevant och nödvändig för utveckling av Bildung.

Studiens tredje frågeställning undersöker hur undervisning kan designas för att stötta eleverna i att uppmärksamma komplexitet. I studiens två cyklerna deltar olika antal elever där relativt få elever deltog i cykel 1. Möjligtvis skulle resultatet i cykel 1 blivit annorlunda om ett större antal elever hade deltagit. Det finns också en skillnad i ämnesinnehåll, där cykel 1 handlar om batterier och cykel 2 om

organiska miljögifter. Detta kan också ha bidragit till skillnader i resultatet mellan de olika cyklerna. Syftet med studien är dock inte att jämföra de två cyklerna utan att undersöka hur undervisning kan designas för att stötta eleverna att uppmärksamma komplexiteten i hållbarhetsfrågor. Då komplexitet inte uppmärksammades i någon större utsträckning i cykel 1 vill vi understryka att hållbarhetsfrågor i kemiundervisning inte nödvändigtvis erbjuder möte med komplexa frågor eller synliggör komplexitet i elevers resonemang.

I studien utvecklas både en didaktisk modell och tre designprinciper. För att diskutera hur dessa kan komplettera varandra utgår vi från tre didaktiska frågor (Wickman, 2014): *Vilket* innehåll ska undervisas? *Hur* ska detta innehåll undervisas. *Varför* detta innehåll och *varför* dessa metoder? En didaktisk modell kan stötta lärare i att utveckla och använda ett gemensamt språk som behövs för att diskutera (i detta fallet) vad komplexitet i hållbarhetsfrågor inom naturvetenskapliga ämnen kan vara och hur det kan analyseras. Modellen kan också vara ett verktyg för didaktisk analys och ett redskap att reflektera över och motivera sina val i undervisningen, vilket knyter an till *varför*-frågorna ovan. Wickman (2014) menar också att ett syfte med didaktisk forskning är att ge lärare redskap att göra dessa val och motivera dem utifrån vetenskaplig grund. Däremot ger den didaktiska modellen som utarbetas här ingen konkret vägledning i *vilket* innehåll som ska väljas och *hur* detta ska undervisas. Här kan däremot designprinciper precisera hur kemiundervisning om komplexa hållbarhetsfrågor kan planeras och genomföras.

En av de tre designprinciperna är att utgå från frågor i forskningens framkant, vilket kan vara ett sätt att stötta eleverna i att uppmärksamma komplexitet i hållbarhetsfrågor och då framförallt vad gäller frågornas osäkerhet. En annan princip är att välja ett innehåll så att eleverna efterfrågar kunskaper i kemi i sina resonemang. Ytterligare en designprincip är att explicit efterfråga olika perspektiv för att ge eleverna möjlighet att uppmärksamma motstridiga perspektiv och värderingar i högre utsträckning. De två första av dessa designprinciper kan ge vägledning om *vilket* innehåll som kan undervisas och den tredje om *hur* undervisningen kan organiseras. Många lärare efterfrågar nya metoder och stöttning i att arbeta med hållbarhetsfrågor ur ett pluralistiskt perspektiv inom naturvetenskapliga ämnen (t.ex. Borg et al., 2012; Ekborg et al., 2013). Vår intention är att den modell och de designprinciper som utvecklas här kan vara ett stöd för lärare vid design av undervisning som syftar till att stötta elever i att uppmärksamma komplexitet i hållbarhetsfrågor. Hur den didaktiska modell som utvecklas här och designprinciper kan komplettera varandra behöver dock undersökas vidare.

Slutsats

Genom den didaktiska modelleringen kunde fyra olika typer av överväganden identifieras, som samtliga behövs för att synliggöra komplexitet. Dessa överväganden användes för att utarbeta en didaktisk modell. Som en del av den didaktiska modelleringen genomfördes också en designstudie som utvecklade tre designprinciper. Tillsammans med modellen kan dessa vara ett stöd för lärare vid planering, genomförande och utvärdering av kemiundervisningen utifrån komplexa hållbarhetsfrågor. Studien visar också att kemiundervisningen kan bidra till elevernas naturvetenskapliga medborgarbildning.

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Paper II

Exploratory considerations in chemistry education—didactic modelling for complexity in students' discussions.

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Introduction

Real-life issues often appear unpredictable, uncertain and permeated by complexity, and the scientific knowledge learned in school usually provides insufficient preparation for dealing with these issues. Science education needs to address real-life issues and complexity to prepare young people for life's challenges. Accordingly, education should include activities where students can encounter real-life issues and experience complexity. Furthermore, science education also needs to inculcate in students a willingness to engage with scientific issues and in scientific practices. According to research, one fruitful way to increase student participation in science education might be to allow students to experience the tentativeness in science. Therefore, this study aims to explore how complexity is expressed in students' discussions, and how this complexity relates to the exploratory nature of chemistry.

Background

Science education for citizenship

One of the main purposes of science education is to support students' development of scientific literacy (SL). However, there is no consensus on the definition of scientific literacy; the word is usually used to 'express what should constitute the science education of all students …' (Roberts, 2007, p. 729). He describes two conflicting curriculum perspectives on scientific literacy, Vision I and Vision II: 'Vision I gives meaning to SL by looking inward at the canon of orthodox natural science, that is, the products and processes of science itself' (Roberts, 2007, p. 730). On the other hand, 'Vision II derives its meaning from the character of situations with a scientific component, situations that students are likely to encounter as citizens' (Roberts, 2007, p. 730). Vision II includes real-life issues, and thereby aspects of uncertainty and risk, thus presenting a less uniform and often more student-centred approach to science education (Roberts, 2007). Vision II is related to a *Bildung*-oriented science education (Sjöström, Frerichs, Zuin, & Eilks, 2017; Wickman, 2014). *Bildung* includes personal and societal development, and solidarity and responsibility for acting towards positive changes in society (Elmose & Roth, 2005). This is also in line with Brickhouse & Kittleson (2006), who request a science education which enables students to develop a willingness to participate in scientific practices aimed at developing an ecologically and socially just society.

Relevance and authenticity in chemistry education

A review of the use of *relevance* in science education states that the concept is not clearly defined (Stuckey, Hofstein, Mamlok-Naaman & Eilks, 2013). Relevance is often regarded as a synonym for students' interest or as their personal perception of meaningfulness (Stuckey et al., 2013). They propose a model which includes dimensions in time (today and in the future), motivation (intrinsic–extrinsic) and goals (individual, societal and vocational) as a tool to discuss different aspects of relevance in education and in curriculum.

There is an abundance of studies regarding students' opinions about relevance in chemistry education. Most of them indicate that students find it difficult to connect science content knowledge to their everyday life and the science taught in school is seldom considered

meaningful (e.g., Aikenhead, 2006). Additionally, several studies imply that scientific content and pedagogical methods are seldom perceived by the students to be relevant (e.g., Hofstein, Eilks & Bybee, 2011). Others argue that science is often presented in a way that gives the impression of a subject which is hard to learn, devoid of connections to everyday life and where there is no room for creativity, emotions and morals (e.g., Brickhouse, 2011). This contributes to the students' image of science as uniform and absolute (e.g., Kelly, 2014; Lemke, 1990). However, these studies are conducted through interviews or questionnaires, requesting students' opinions regarding chemistry education, aiming to identify challenges and problems within science education. Therefore, it seems more research regarding how to address these challenges is needed, and more in-situ studies required to develop tools for teachers to use in their efforts to challenge the prevailing teaching traditions.

Different aspects of authenticity have been widely discussed in science education research (Anker-Hansen & Andreé, 2019). One aspect is personal authenticity, which concerns the opportunities students are given to find value and meaning in what they are expected to do and learn (Murphy, Lunn, & Jones, 2006). According to Lundegård (2018) this relates to how the subject content matter concerns the students and how activities enable students to connect the subject matter content to themselves and their personal lives. Connection to everyday life is often regarded as essential to enhance students' perception of chemistry education as relevant (Aikenhead, 2006; Broman & Simon, 2015). However, real-life issues often appear to be uncertain, and the 'pure science' learned in schools is often not useful for solving these issues (Aikenhead, 2006; Roth & Barton, 2004). Brickhouse (2011) argues that, 'The knowledge that is taught in schools is often decontextualized, abstract, and difficult to apply to real world contexts' (Brickhouse, 2011, p. 199). To develop meaningful chemistry knowledge, students need support to relate chemistry to their lives and to their role as citizens in society (e.g., Childs, Hayes & O'Dwyer, 2015).

Towards a participatory chemistry education

Science education is often criticised for being exclusive and for contributing to a context where many students feel alienated (Brickhouse, 2011). However, individual students cannot be held responsible for a lack of willingness to participate in science education; this must rather be regarded as a science curriculum problem (Brickhouse, 2011).

To increase student participation, education must pay more attention to students' own questions and ideas, and focus less on teaching them to repeat what teachers or other experts have already said and done (Brickhouse, 2011; Roth & Barton, 2004). Education which includes students' own questions might interest a more diverse group of students (Brickhouse, 2011; Orlander, 2011). The challenge, however, is knowing in advance what interests the students will introduce, and the teacher must trust students to pay attention to what is relevant for them (Orlander, 2011). Brickhouse (2011) asks:

> Perhaps we should be paying more attention to actual scientific competences in complex environments in and out of schools, rather than relying on test scores, and learning about desires and passions of children and adolescents and how these may be linked to science? (Brickhouse, 2011, p. 202)

Basu & Calabrese Barton (2010) have developed a model for a democratic science education through a researcher-teacher-student collaboration. They argue that one way of increasing student authority in the classroom and allowing students' voices to be heard, is to present science as tentative, with opportunities to discuss different evidence-based opinions. This

allows the students' perspectives and ideas to be valued, instead of more traditional methods where students simply apply facts they are taught by the teacher. The teachers also expressed a desire to value students' funds of knowledge to improve classroom equity. Here the teachers emphasised connecting to students' everyday life experiences to incorporate students' knowledge from outside of school into the education.

Calabrese Barton, Tan and Rivet (2008) discuss *hybrid spaces* where school science discourse and everyday-life discourse come together to transform into new knowledge and discourses. Calabrese Barton et al. (2008) write:

> It is in these hybrid spaces where teachers' structural and pedagogical choices allow them to share authority with their students—allowing students to take on, however momentarily, the identity of an expert rather than a novice—and where students can feel what they have to contribute matters and is of value (Calabrese Barton et al., 2008, p. 98).

To conclude, research has shown the importance of dealing with authentic real-life issues in chemistry education. This allows real-life and chemistry content knowledge to merge. Additionally, these issues seem to contribute to an image of chemistry as tentative, which can enable students to participate through their own funds of knowledge. However, more research is needed to analyse how activities in chemistry education can be designed to enable students to experience chemistry as tentative.

Complexity in chemistry education

The notions of *complexity* and *complex issues* are widely used in both science curricula and research in science education (e.g., Sadler, Barab & Scott, 2007). Clear definitions, however, are elusive. According to the Cambridge Dictionary, complexity can be defined as 'the state of having many parts and being difficult to understand or to find an answer to' (Cambridge dictionary, 2019). Complexity is also described as the interactions between different factors and attempts to clarify how these factors interact. Furthermore, since the outcome of these interactions are hard to predict, uncertainty is closely related to complexity (Rucker & Geronimo, 2017).

Complexity in chemistry education has often been discussed in relation to socio-scientific issues (SSI) and environmental issues. SSI are science-based, but with a potentially significant impact on society (e.g., Sadler & Zeidler, 2005). They are authentic, contemporary, complex and often controversial, involving multiple stakeholders with conflicting interests (Ratcliffe & Grace, 2003; Simonneaux, 2008). Research indicates that SSI can increase students' interest in science as well as their scientific literacy (e.g., Chang Rundgren & Rundgren, 2010). Environmental issues are usually permeated by complexity, e.g., through conflicting perspectives on the issue and its potential solutions. Furthermore, making this complexity visible is an important part of science education for citizenship (Öhman & Öhman, 2012). Unfortunately, this complexity is often neglected within science education (Sund, 2015).

One way to approach complex issues which focus on scientific content is Context-Based Learning, or CBL (Pilot & Bulte, 2006). CBL is used as a frame to guide students from a contextual challenge which includes chemistry content related problems towards a solution to the challenge. Here, the students are expected to request and learn chemistry knowledge on a *need-to-know* basis, and the context is supposed to give meaning to the scientific concepts (Bulte, Westbroek, De Jong & Pilot, 2006). Context-based chemistry has been shown to be a

fruitful approach for increasing students' interest and motivation (Broman, Bernholt & Parchmann 2018).

The analysis of complexity is often connected to the issue itself, i.e., as the inherent complexity within the issue and how the students perceive this complexity (e.g., Sadler et al., 2007). Another approach is presented by Knain (2015), where the scale of complexity is not found within the issue itself, but rather in how it comes to be expressed in the students' discussions: 'We understand complexity as a quality of the unfolding discourse rather than an inherent characteristic of the issue' (Knain, 2015, p. 113).

In a previous study, a model for complexity in students' deliberations was developed (Dudas, Rundgren & Lundegård, 2018). The model was developed through an analysis of the considerations the students were dealing with in their discussions. In the analysis, four different kinds of considerations emerged, which were used to extract the model below (Table 1).

Table 1. Didactic model for complexity in students' deliberations regarding sustainability issues (After Dudas et al., 2018)

Factual considerations Factual knowledge is required to deal with the consideration	
With sufficient facts Factual knowledge is available.	**With insufficient facts** Factual knowledge is not (yet) available for students, teachers or scientists.
Moral considerations Factual knowledge, values and other experiences are required to deal with the consideration.	
With sufficient facts Factual knowledge is available.	**With insufficient facts** Factual knowledge is not (yet) available.

In the present study, we analyse complexity from Knain's (2015) perspective, i.e., the complexity as it unfolds in the students' discussions. We regard complexity in discussions as including attempts to discern how different factors interact and as being closely related to uncertainty. We aim to explore this through an analysis of the considerations that the students pose in relation to the chemistry content.

Aim and research questions

An overarching objective of this paper is to explore how chemistry education can contribute to science education for citizenship. Research has shown the importance of dealing with authentic real-life issues and of enabling student encounters with complexity in chemistry education in order to increase student participation in scientific practices. Therefore, this study aims to analyse how complexity evolves in students' discussions, and how this complexity relates to the exploratory nature of chemistry. Drawing on our previous model for complexity in students' deliberations, this study also aims to analyse how the model can be further developed in a new context.

The research questions are:

RQ1: What kinds of considerations can be discerned in the students' discussions?
RQ2: How will the didactic model for complexity in students' discussions evolve from a chemistry content issue?

RQ3: In what ways can activities be designed to enable students to experience chemistry as exploratory?

Methodology

Didactic modelling

The purpose of didactic modelling is to develop models for teachers to use in didactic design and analysis. A didactic model is often visualised through a conceptual scheme (Wickman, 2012). According to Wickman, Hamza & Lundegård (2018), the phases *extraction*, *mangling* and *exemplification* are included in the development of didactic models. In the extraction phase, the processes which are pertinent to the modelling are analysed. In this phase, learning theories are processed together with the data in order to develop a didactic model. In mangling, previously extracted models are used in new contexts for adjustments. An extracted model must be tried and used in practice to prove both its usefulness and limitations. Extraction and mangling are often done simultaneously in cyclic interventions. Exemplification means to use the model in a different context to demonstrate its applicability.

The aim of didactic modelling is not to construct a complete or final model but rather to develop tools that need further and continuous development in practice. Didactic modelling is conducted through close cooperation between theory and practice, teachers and researchers.

In this study we depart from a previously extracted model for complexity in chemistry education (Dudas et al., 2018) with the purpose of mangling the model in a new context. The previous model was extracted from an activity based on a pluralistic perspective on sustainability issues. In the present study, we explore how the model can be mangled in an activity where the chemistry content (i.e., metabolism in the human body) is focused, rather than the societal aspects.

Theoretical framework

This study is based on a pragmatic perspective on learning, grounded in the work of John Dewey. One fundamental pragmatic perspective is that meaning-making takes place in a context and through encounters, both socially with other people, and physically with artefacts (Dewey, 1938/1997). Another essential idea is that learning can be viewed in terms of actions and that knowledge exists when it is used in a context (Cherryholmes, 1999). Therefore, to comprehend a certain content, the content must also be used in a context where it is needed. The meaningfulness of knowledge can be judged from how students use it to deal with an activity. Dewey (1938/1997) argues that encounters with the unpredictable and still unknown establish 'an active quest for information and for production of new ideas' (Dewey, 1938/1997, p. 79). Thus, learning involves testing ideas by reflecting upon their consequences.

Analytical methods

The analytical tools Practical Epistemology Analysis (PEA) and Deliberative Educational Questions (DEQ) are based on a pragmatic framework. PEA was developed by Wickman & Östman (2002) to analyse learning and meaning-making in classroom discussions. However, the unit of analysis is not the individuals' utterances, but the mutual transactions in the discourse. PEA departs from the specific purpose of the activity at hand. Student encounters engender gaps which can be filled by relations.

A further development of PEA is DEQ (Lundegård & Wickman, 2007) which can be used to visualise the gaps and relations emerging in the activities. This analytical method involves

rephrasing the gaps discerned in the students' discussions to deliberative questions. DEQ have previously been used to analyse students' choices derived from conflicts of interest in discussions regarding sustainability issues. In the present study we are inspired by Lundegård & Wickman's (2007) work and use DEQ as a method to explore the considerations the students introduce in their encounters with the chemistry content. Lundegård & Wickman (2012) showed how each person's utterance challenged and enabled the other participants to 'take new initiatives in the deliberation' (p. 165) and how this encouraged the students to sketch new ideas or explanations.

The setting

Empirical material

This study was conducted at one upper secondary school in Stockholm in close collaboration with three science teachers. Fifty-six students in the third year of a natural science programme participated. Three groups were recorded on video for approximately ten hours each. The teachers put the students together in heterogeneous groups of four to six. A total of fifteen students were recorded. The groups were selected from those students who had given permission to be recorded.

Students' activity

The analysed activity was part of a larger unit covering about 30–40 hours in the courses Chemistry 2 and Biology 2. The purpose of the unit was to learn about metabolism in the human body and different factors influencing glucose level in the blood. Prior to the activity analysed in this study the students had had theory classes on metabolism.

The activity was conducted in three parts: the students started with the preparation phase where they were informed about the purpose of the activity, i.e., to analyse how different food, stress, exercise and rest influence the level of glucose in the blood. An essential part of the activity was a practical where the students ate a certain food for breakfast then measured the glucose level in their blood. The students prepared the practical by deciding what kind of food to eat for breakfast. The instructions were that the food should be either fat, fast carbohydrates or slow carbohydrates, and as pure as possible; e.g., the fat group would eat only olive oil, the fast carbohydrate group only white toast and the slow carbohydrate group only rye porridge. The groups were also instructed to formulate their own research question to correspond with the purpose of the activity, e.g., *How does glucose level change when one eats rye porridge and is exposed to stress, rest or exercise?* These research questions framed the students' work through the activity.

The second part was the practical where the students ate the chosen food at school and measured their glucose levels over two hours. During this time some of the students exercised, some rested and others were exposed to stress to see if and how these factors influenced glucose levels in the blood.

During the third part students interpreted and analysed their collected data, i.e., the values and curves describing the changes in glucose levels. The students also designed a scientific poster to present their analysis and results, and to answer their research question.

The practical, the analysis of the collected data and the production of the poster were recorded on video. All relevant parts of the discussions were transcribed and analysed with PEA and DEQ. The activity was designed to enable students to experience chemistry as exploratory, where different perspectives on chemistry content could be discussed, thus enabling them to

contribute with their own ideas, questions and knowledge. The idea was also for the activity to relate the chemistry content to students' everyday lives. We will use *chemistry content issue* to describe issues where the focus is the chemistry content, rather than the societal perspectives on the issues. In this paper the issue regards the human metabolism.

Analytical procedure

The transcript below shows an example of how the DEQ analysis was conducted in this study. The purpose of the students' discussion was to analyse how factors such as different foods, stress, exercise and rest influence the level of glucose in the blood. The students below had olive oil for breakfast and are discussing the level of glucose in their blood, which has recently been measured.

Excerpt one

1. Mark: But why did *the blood sugar level increase* for me and Ellen *after we had eaten fat*?
2. Zoe: F**k!
3. Peter: This is completely …
4. Zoe: I am really *confused.*
5. Peter: Why should the sugar increase when we eat fat?
6. Mark: Yeah, that is *really strange*.

Here a relation is established between *it is confusing and strange*, and *sugar is released when eating fat.* This gap can be formulated as the DEQ: *Is the increased level of blood sugar after eating fat strange or not?*

7. Zoe: However, *there is stored glycogen,* which *comes out as blood sugar*.

Relation: *the increased blood sugar level* and *stored glycogen*.
DEQ: *Is stored glycogen part of the explanation for the increasing level?*

8. Peter: Aww, but the fat?!
9. Zoe: Wtf does the fat do?

Relation: *could this happen?* and *after eating fat*.
DEQ: *Is there a possible relation between intake of fat and the release of stored glycogen?*

10. Mark: But hey, wait, when the food is eaten, energy is needed to *digest it*, and then *energy is released.*

Relation: *the released energy* and *the digestion of food.*
DEQ: *Could it be that the increased level is caused by the body's need to digest?*

Note that the term 'or not' at the end of the first DEQ above implies that this a question of choice. We assume the 'or not' question to be implicit in all the DEQ presented.

In this study we will use *considerations* to represent what the students need to deal with in order to move on in their discussions, and *DEQ* to represent the DEQ that emerge in the analysis. However, considerations and DEQ are not interchangeable as the DEQ are not identical to the students' questions, but rather, useful analytical tools to make the considerations visible.

Results

The excerpts below were chosen since we consider them to illustrate categories emerging in all groups' discussions. The purpose of all discussions was to analyse the glucose level and how this level can be influenced by food, exercise, rest and stress.

What kinds of considerations can be discerned in the students' discussions?

Two different kinds of considerations were discerned: *factual and exploratory considerations.* In the analysis we consider the emerging *factual* and *exploratory* DEQ to represent the students' considerations. Both factual and exploratory DEQ could be found in all groups' discussions. In total, 162 DEQ were found in the analysis. Eighty-one of these were factual, and eighty-one were exploratory.

The two excerpts below are used to illustrate how these two categories are expressed in the students' discussions.

Factual considerations

The factual considerations are considerations to which the answer is known by others (e.g., other students, the teacher or other experts). These usually relate to chemistry content knowledge. In the excerpt below, a group of students who had rye porridge for breakfast are trying to disentangle why blood glucose level increased after 15 minutes.

Excerpt two

1. Sam: But when carbohydrates start to be digested in the mouth by amylase, will one absorb any energy at all?
2. Anna: Mmm.
3. Sam: Do you?
4. Ken: Yes, yes.
5. Peter: That also gets absorbed into the blood.
6. Sam: Are you sure?
7. Ken: Yeah, I remember that you can absorb some glucose in your mouth.
8. Peter: I suppose that's the reason quick carbohydrates come quickly, since quite a lot gets absorbed into the blood in the mouth already.
9. Sam: Hmm.
10. Anna: Yes, exactly.

From this excerpt we formulated the following DEQ:
DEQ 1: Does one absorb any energy when the carbohydrates are digested in the mouth, or not?
DEQ 2: Does the glucose digested in the mouth become absorbed into the blood, or not?
DEQ 3: Is this the explanation for why fast carbohydrates are fast, or not?

We consider DEQ 1–3 to represent factual considerations.

Exploratory considerations

The exploratory considerations are considerations to which multiple answers or solutions are possible. Exploratory considerations are illustrated through the excerpt below, where the group of students who had olive oil for breakfast are analysing the levels of glucose in their blood. The students' hypothesis was that fat should not affect the level of glucose. However, it turns out that Mark's glucose level actually increased after the intake of olive oil and the students are struggling to explain why his glucose level does not follow the predictive curve.

Excerpt three

1. Zoe: How long do you travel to school, where do you live, how do you get to school?
2. Mark: Well, it's about 30 minutes; I live in Oakhill.
3. Zoe: Did anything happen on the metro?
4. Simon: Did you ride your bike?
5. Mark: No, I went with the metro.
6. Zoe: Did anything happen there?
7. Mark: No …
8. Zoe: Did you read anything, or did you listen to death metal?
9. Mark: No, really, nothing special.
10. Zoe: No butterflies in your stomach …?
11. Mark: I meet Beatrice (a classmate) on …
12. Zoe: Ohh, ohh, that's it! (joking)
13. Mark: … outside the metro and we talked, but I don't know …
14. Simon: Do you have a pollen allergy?
15. Mark: Yes …
16. Everybody: Ohhh!
17. Mark: Ahhh!
18. Somebody: That is stress!
19. Zoe: Are you getting stressed by pollen?
20. Mark: No, no, but your body is stressed because of the pollen.

From this excerpt we formulated the following DEQ:
DEQ 4: Can Mark's unexpectedly high levels of blood glucose be explained by how he got to school?
DEQ 5: Did anything happen on the metro that might have influenced the inflated level of glucose?
DEQ 6: Could biking to school have influenced Mark's blood glucose level?
DEQ 7: Could reading or listening to music have influenced Mark's blood glucose level?
DEQ 8: Could a pollen allergy influence Mark's blood glucose level?
DEQ 9: Can pollen cause stress in Mark's body?

We consider DEQ 4–8 to represent exploratory considerations and DEQ 9 to represent a factual consideration.

How will the didactic model for complexity in students' discussions evolve from a chemistry content issue?

In the excerpt below, the students are dealing with both factual and exploratory considerations. The group, who ate slow carbohydrates (i.e., rye porridge) for breakfast, are discussing why there is a peak in Sam's glucose curve after 45 minutes.

Excerpt four

1. Sam: But if it happens at exactly the same time?
2. Ken: Oh, yes.
3. Sam: And the adrenaline is released.
4. Anna: And then the insulin is decreased, it is inhibited, and the blood sugar is increased.
5. Sam: But maybe it takes a little while, it shouldn't increase just like that—poff! — right?
6. Peter: Yeah.
7. Sam: Because it doesn't happen directly.

8. Ken: But maybe it was already on the way up, like, when it was at the bottom … here (points on the graph) it started to curve up ...
9. Peter: At the same time as the slow carbohydrates probably came down to …
10. Ken: But it could also be that ...
11. Sam: Yes, exactly.
12. Peter: … small intestine.
13. Sam: No, it could be like that.
14. Anna: Doesn't it take longer?
15. Peter: It did take 45 minutes, that is a long time.
16. Anna: Yes, that is quite long.
17. Ken: Well, can we then say that this peak is connected to stress, in combination with the food starting to be digested …?
18. Anna: But I have heard that stress inhibits the digestion, so, so …

From this excerpt we formulated the following DEQ:
DEQ 10: Does adrenaline cause a decrease of insulin?
DEQ 11: Is that a fast process?
DEQ 12: Did the effect of adrenaline coincide with the appearance of glucose from slow carbohydrates in the blood?
DEQ 13: Might stress together with food cause this 'peak'?

We consider DEQ 10–11 to represent factual and 12–13 to represent exploratory considerations.

To analyse how the preceding model developed in the new context, we used the previous model for complexity as an analytical tool. Our attempt/approach was to categorise the considerations emerging in the new context into the four previous categories: factual considerations with sufficient facts/insufficient facts, value-based considerations with sufficient facts/insufficient facts (Table 1).

We consider it possible to merge the factual considerations in the present study with the previous category—factual considerations with sufficient facts. The exploratory considerations in the present study share many characteristics with factual considerations with insufficient facts. However, the insufficiency and uncertainty have different characteristics in the two contexts. Additionally, by using the notion of *exploratory* we would like to emphasise the tentativeness and possibilities for further investigations. The analysis indicated that there was an absence of moral considerations in the new context. A possible explanation might be that values and moral issues were not explicitly emphasised in this activity.

The analysis resulted in the following model:

Table 2. Didactic model for complexity in students' discussions

Factual considerations Considerations with answers known by others (DEQ 1, 2, 3, 9, 10, 11)	**Exploratory considerations** Considerations with more than one possible answer (DEQ 4, 5, 6, 7, 8, 12, 13)

In what ways can activities be designed to enable students to experience chemistry as exploratory?

The results indicate that one way to enable students to experience chemistry as tentative can be to design activities where the students encounter unpredictable or inexplicable results. In the present study this caused uncertainty regarding how to make the chemistry content knowledge useful when dealing with real-life issues. This enabled the students to introduce exploratory considerations. As more than one answer is possible the students can experience chemistry as tentative. This enables students to contribute and participate through their own funds of knowledge. This is illustrated in excerpt three, where the students contributed with different possible explanations about how different everyday factors might have influenced Mark's blood glucose level. Therefore, drawing on real-life issues seems to be a way to enable students to experience chemistry as exploratory.

Summary of results

Two different kinds of considerations were discerned in the students' discussions—factual and exploratory considerations. The new model for complexity consists of these two categories. Furthermore, the results indicate that to depart from real-life issues with inherent uncertainty in chemistry content knowledge might be a worthwhile approach to enable students to experience chemistry as exploratory.

Discussion and conclusions

Two different kinds of considerations emerged in the students' discussions in this study. Factual considerations often relate to the 'pure' chemistry content and are in line with how scientific knowledge has traditionally been presented in schools, i.e., as absolute, with one right answer, and unaffected by values, or cultural and societal perspectives (e.g., Aikenhead, 2006; Brickhouse, 2011; Roth & Barton, 2004). They also correspond to the tradition of students being expected (and thus limited) to repeat and learn what teachers and other experts already know (Brickhouse, 2011). This has preserved the image of science as a subject with irrefutable answers and devoid of creativity, leaving many students feeling alienated. Nevertheless, chemistry content knowledge is essential for scientific literacy—'everybody agrees that students can't be scientifically literate if they don't know any science subject matter' (Roberts, 2007, p. 735). Factual considerations are an indispensable part of chemistry education, but if students only encounter this kind of science, there is a risk of maintaining the image of science as non-exploratory, uniform and absolute.

Exploratory considerations emerge when students encounter uncertainty about how to make chemistry knowledge meaningful in real-life contexts. It is not about insufficient knowledge, but considerations to which different chemistry knowledge based answers or explanations are possible. The discussion in excerpt three illustrates how the students negotiate the use and understanding of the chemistry content in relation to the real-life issue at hand. Here, the students are allowed to pose their own ideas, based on chemistry content knowledge, to solve the problem: **Simon**: *Did you ride your bike?* (chemistry knowledge: adrenaline affects the level of glucose); **Zoe***: Did you read anything, or did you listen to death metal?* (chemistry knowledge: stress affects the level of glucose); **Simon**: *Do you have a pollen allergy?* (chemistry knowledge: pollen might cause stress). Exploratory considerations enable the students to experience science as tentative, as a discussion where different evidence-based perspectives are offered. This could be a way to enable students to participate through their own funds of knowledge, and thereby increase student participation in chemistry education (Basu & Calabrese Barton, 2010). In the present study the students are moving on from what they already know to create new knowledge regarding specific contexts where knowledge about metabolism is needed. Here, we would like to stress that it is not about abandoning

scientific knowledge, but rather about giving students opportunities to use and create their own knowledge in a specific context.

The factual and exploratory considerations deal with epistemology. Accordingly, these categories in the models engage with how we model chemistry education to deal with understandings of how reality works. In the present study, there was an absence of morals-related considerations. However, from a pragmatic perspective, subject matter content is inseparable from values. The students do not only learn the facts, but also opinions about the facts and whether they like the content or not (Dewey, 1938/1997). The students are continuously making choices about how to proceed, how to act and what to focus on, as all these acts involve values. Hence, a value-free education is difficult to imagine (Wickman, 2004). We regard the value-related categories in the previous model as dealing with moral issues, i.e., how things ought to be or how we ought to act. Thus, the value-related categories in the previous model regard how we should model education to support moral considerations. The present activity did not explicitly relate to how one ought to act. This might be a possible explanation for the lack of morals-related considerations in the present study.

Research emphasises the importance of connecting school science to students' everyday lives (e.g., Aikenhead, 2006; Roth & Barton, 2004). It is often claimed that to enhance the authenticity and relevance of chemistry education, students need support to make connections between chemistry content and their everyday lives (Childs, Hayes & O'Dwyer, 2015).

The activity in the present study, draw on a Vision II perspective through a real-life issue where chemistry knowledge is needed (Roberts, 2007). The idea was to enable the students to relate scientific content to their everyday life experiences. The results imply that when students have insufficient scientific knowledge to interpret the data, they turn to real-life experiences to find explanations. In excerpt three, they draw on their experiences about how they got to school and how this might have influenced the level of glucose. The students advance from their own considerations in relation to the chemistry content to develop their own ideas throughout the activity. These considerations can also challenge and enable other students to try new ideas and explanations (Lundegård & Wickman, 2012). A science education where students can expand their knowledge from their own and other's considerations could possibly be interesting for a more diverse group of students (Brickhouse, 2011). From a pragmatic point of view, learning content must also be based on the use of that content in a situation where it is needed (Cherryholmes, 1999). In the present study chemistry knowledge is substantially required when the students are dealing with their own considerations. Furthermore, the chemistry knowledge becomes meaningful through the activity (Cherryholmes, 1999).

In order to enable students to contribute to positive and responsible changes in society, we need to develop a science education in which students are willing to participate (Elmose & Roth, 2005; Brickhouse & Kittleson, 2006). It has previously been shown that both SSI and CBL increase students' interest in chemistry education (e.g., Chang Rundgren & Rundgren, 2010; Broman et al., 2018). The activity analysed in this paper relates to CBL, as students request content knowledge on a need-to-know basis, and the context is expected to give meaning to the chemistry knowledge (e.g., Bulte et al., 2006). The activity also relates to SSI, as the students encounter a dilemma which is complex, unstructured and having more than one possible answer (Ratcliffe & Grace, 2003; Simonneaux, 2008). However, the activity is not designed to focus on the societal or moral perspectives of metabolism (e.g., obesity or diabetes). It could, however, be possible to extend the activity to include these perspectives as well.

It is often claimed that the science taught in school is remote from the way scientists work with science, and school science is accused of presenting a fake image of scientists' work (Brickhouse, 2011). As the exploratory considerations are investigable, one approach to relate chemistry education to scientists' work might be to let students construct investigable questions and conduct practical inquiries from exploratory considerations. The students would not only learn scientific content, but also how science can be conducted. However, this is not the objective of this study, and needs to be further analysed.

In this study, we explore complexity as it unfolds in the students' discussions (Knain, 2015). The analysis shows how the students facilitate complexity through their considerations in the discussions. Complexity is here considered to consist of attempts to discern how different factors interact with and are closely related to uncertainty (Rucker & Geronimo, 2017).

Both factual and exploratory considerations relate to complexity in terms of dealing with attempts to discern how different factors interact. Exploratory considerations are closely related to uncertainty in relation to the chemistry content, and thus complexity in students' discussions. An education from a Vision II perspective often leads the students' discussions down unpredictable paths (Roberts, 2007). Furthermore, Dewey (1938/1997) emphasises the importance of encounters with the unknown, as he argues that these are the foundation of new ideas. Real-life issues are often contentious and uncertain, and the science learned in school is usually insufficient for solving a problem at hand (Brickhouse, 2011; Roth & Barton, 2004). In the present study, the students often demonstrate theoretical knowledge about how carbohydrates, stress and adrenaline affect the level of glucose. But when it comes to real-life contexts, this knowledge is not easily applied to an explanation of how and why blood glucose levels are changing. This is illustrated in excerpt one, where the students 'know' that blood glucose levels should not be affected by the intake of fat. The emerging conflict between the chemistry content knowledge (fat should not affect the level of glucose) and the real-life experience (increased glucose level after intake of fat) introduces an uncertainty. Thus, the students need to deal with an exploratory consideration regarding *what might be possible explanations for the increased blood sugar level after Mark and Ellen ate fat?*

Factual considerations relate to lack of chemistry content knowledge. Therefore, factual considerations do not explicitly enhance complexity from an uncertainty perspective. Nevertheless, they are often needed to disentangle the chemistry content knowledge related to the exploratory considerations. However, a discussion permeated merely by factual considerations can hardly be regarded as complex due to a lack of uncertainty.

This study also aims to mangle the previous didactic model in a new context. We propose a new model for complexity in students' discussions consisting of factual/exploratory considerations (Table 2). The exploratory considerations share many characteristics with the previous category—factual considerations with insufficient facts. Nevertheless, the uncertainty in exploratory considerations is not about lack of scientific knowledge, but how to apply chemistry knowledge to real-life issues. We consider the exploratory considerations to be an important contribution to the previous model. Exploratory considerations seem to facilitate hybrid spaces, where new knowledge can be created through a consolidation of chemistry content knowledge and the students' everyday experiences. Hybrid spaces can also increase student authority in the classroom by regarding students' voices as worthwhile, which is important to enhance student participation in science education (Brickhouse, 2011; Basu & Calabrese Barton, 2010; Calabrese Barton et al., 2008).

This paper is based on one study in one upper secondary school, which implies that more studies are needed to support the claims made here. In future research, the model can be further explored in different contexts in cooperation with teachers. It would also be interesting to analyse how the model could support teachers in didactic analysis and design.

Conclusions and didactic implications

One of the aspects of science education for citizenship explored in this paper is how education can be designed to contribute to students' opportunities and willingness to participate in scientific practices. The study shows that chemistry education needs to include uncertainty, and not merely focus on factual knowledge, in order to facilitate complexity and exploratory considerations in students' discussions. Exploratory considerations can enable students to experience chemistry as tentative, with opportunities for them to contribute with different perspectives. This is one possible approach to increase student participation in chemistry education and to enhance shared authority in the classroom.

Another aspect of science education for citizenship is to facilitate student encounters with real-life issues which they are likely to confront as citizens (Roberts, 2007). The results indicate that activities based on real-life issues invite the unpredictability and uncertainty needed for experiencing the exploratory nature of chemistry.

The results of this study suggest that the model of factual/exploratory considerations could be a useful tool for teachers in the didactic analysis and design of a more participatory chemistry education.

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