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Towards *Bildung*-Oriented Chemistry Education

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Abstract This paper concerns *Bildung*-oriented chemistry education, based on a reflective and critical discourse of chemistry. It is contrasted with the dominant type of chemistry education, based on the mainstream discourse of chemistry. *Bildung*-oriented chemistry education includes not only content knowledge *in* chemistry, but also knowledge *about* chemistry, both about the nature of chemistry and about its role in society. In 2004 Mahaffy suggested a tetrahedron model based on Johnstone's chemical triangle. The latter represents the formal aspects of chemistry teaching (macro, submicro, and symbolic) and the top of the tetrahedron represents a human element. In the present paper the following subdivision of the top is suggested (starting from the bottom): (1) applied chemistry, (2) socio-cultural context, and (3) critical-philosophic approach. The professional identity of the *Bildung*-oriented chemistry teacher differs from that of the chemist and is informed by research fields such as Philosophy of Chemistry, Science and Technology Studies, and Environmental Education. He/she takes a socio-critical approach to chemistry, emphasising both the benefits and risks of chemistry and its applications.

1 Introduction

Based on a risk society analysis (Beck 1992; Ekberg 2007), it is reasonable to argue for *Bildung*-oriented chemistry teaching, which in practice would mean including more ethical and socio-cultural perspectives in the teaching. This paper presents a model for content and perspectives in such chemistry teaching. The aim with *Bildung*-oriented chemistry teaching is to develop critical, deliberate and action-competent citizens or, in other words, "chemical literacy" (Shwartz et al. 2005). The latter can be seen as the contribution that chemistry makes to scientific literacy (Laugksch 2000; Roberts 2007; Holbrook and Rannikmae 2009).

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Table 1 Discourse of chemistry

Mainstream discourse on a *Disciplinary* level	Mainstream discourse on a *Societal* level	Desirable reflective and critical discourse of chemistry
Objectivism	Modernism	Meta-perspectives (e.g. socio-chemistry and chemical ethics)
Molecular reductionism	Self-image of chemists: "the central, useful and creative science"	Problematisation (e.g. epistemic distance)
Rationalism: view of the public as "chemophobic"	Unclear aim Industry emphasis	*Bildung*-oriented

Based on a table in Sjöström (2007)

In a previous paper (Sjöström 2007) I problematised the mainstream discourse of chemistry and suggested a complementary discourse, aiming to replace the often too modernistic and reductionistic chemistry discourse with a more socio-critical and holistic one. Such a new discourse would emphasise the role of chemistry as a culture and within a cultural context. As shown in columns 1 and 2 in Table 1, I subdivide the mainstream discourse of chemistry into two levels: *disciplinary* and *societal*.

This paper concerns chemical education based on the desirable reflective and critical discourse of chemistry (column 3 in Table 1), that is, *Bildung*-oriented chemical education, and how it differs from chemical education based on the mainstream discourse (columns 1 and 2 in Table 1). An extensive review of literature relevant for the area constitutes the basis for the theoretical and position-based approach in this paper.

"Bildung" is the German term for a key idea in the Continental educational tradition. In Swedish it is called "bildning" and in Danish and Norwegian "dannelse". However, there is no precise English translation of the concept (Vásquez-Levy 2002), but it is sometimes translated as "liberal education" (Løvlie and Standish 2002), and is also closely related to the concept of "citizenship" (Elmose and Roth 2005). Vásquez-Levy (2002, pp. 118–119) defines the concept of *Bildung* in the following way: "*Bildung* is the process of developing critical consciousness and of character-formation, self-discovery, knowledge in the form of contemplation or insight, an engagement with questions of truth, value and meaning."

Because there is no precise English translation, the German term is used in the international (Anglo-American) educational literature. For example, the journal *Educational Philosophy and Theory* had a special issue on *Bildung* in 2003. In that issue Wimmer (2003, p. 185) wrote that "*Bildung* denotes whatever is not covered by the other central concepts of pedagogical theory such as socialisation, education, and instruction", but that it also stands for them all. It is, according to Wimmer, "the central critical concept of modern pedagogy". The concept is also occasionally used in the international environmental and science education research literature (see e.g.: Marks and Eilks 2009; Mogensen and Schnack 2010; Hofstein et al. 2011).

In the discussion of *Bildung*-oriented chemistry education I will use Johnstone's (1982) triangle describing the disciplinary content in chemistry education, and Mahaffy's (2004) extension of the triangle adding human perspectives as a top of a tetrahedron. I suggest a subdivision of the tetrahedron's top into three levels (starting from the bottom): (1) applied chemistry, (2) socio-cultural context, and (3) critical-philosophic approach. However, before the discussion of *Bildung*-oriented chemistry education I discuss and describe the common discourse in chemistry education.

2 The Common Discourse in Chemistry Education

I use the term “discourse of chemistry” to refer to chemists’ philosophical and political worldviews and values (both explicit and implicit) (Sjöström 2007). The term can also describe a broad societal and historically based flow of ideas, which dominate the conceptions and practices of chemists (including many chemistry teachers) without their necessarily being aware of its influence. Often it is useful to describe chemists’ (including many chemistry teachers’ and chemistry textbook authors’) views of their science and the role of chemistry in society with labels such as positivism, objectivism, reductionism, rationalism, modernism, and sometimes even scientism. These labels will be commented on below, followed by a case and a discussion of the types of knowledge currently emphasised in most school chemistry courses.

2.1 Labels Such as Positivism and Scientism

In a study of discourses in secondary school chemistry textbooks Östman (1996) used labels such as objectivism, atomism, and instrumental rationality to characterise the texts. One characteristic of the studied textbooks, he meant, is “the goal of making humankind the ruler of nature” (p. 49). According to Aikenhead (2006), “[m]ost high school science textbooks attempt to indoctrinate the reader into an ideology of positivistic realism endemic to the traditional science curriculum” (p. 55), and science “teachers tend to favor abstract decontextualized ‘pure science’” (p. 63). Van Aalsvoort (2004) has shown that logical positivism can explain many students’ experience of low relevance in chemistry teaching.

Objectivism is the view that scientific facts are independent of the context in which they are observed. Most scientists see nature as objective and real. In contrast, post-modernists view scientific facts as constructed, relative and context-dependent (Good and Shymansky 2001). Christensen (2009, p. 208) points out that although “[s]cience is traditionally presented as value-free knowledge […,] scientists routinely make assumptions and value judgements about uncertainties that are black-boxed into their research.” Norris (1997) argues for an “epistemic distance”, by which he means, for example, a balance between realism and relativism (see further below).

Another characteristic of the common discourse of chemistry is that “[c]hemistry, by its culture, has been almost blindly reductionist” Whitesides (2004, p. 3634). According to Early (2004, p. 144), contemporary chemistry conveys an atomistic and mechanistic worldview: “[M]echanics (in its classical, quantum, and statistical versions) can rationalize all sorts of interesting things—even aspects of biology. The take-home message [… is] that *submicroscopic components of things are what is ultimately important*”. On receiving the implicit message that the parts are more important than the whole, many students ignore chemistry “and turn their attention to matters likely to have more importance for their lives”.

Rationalism is a view that considers scientific knowledge and methods to be free of values. According to Schummer (1997), the rationalistic view taken by many chemists makes dialogue with the public difficult: “[T]he main barrier of ecological dialogue between chemists and the public is the exclusive claim for rationality as part of the professional ethics of chemists.” A rationalistic view is often connected to the opinion that it would be good if scientific experts were given increased political influence.

Furthermore, many chemists are “progress optimistic”, as indicated by the prevalence of the approach that assumes that problems in society caused by science can be solved by even more science and technology. This way of thinking is typical of modernism and, in an extreme form, is sometimes called "scientism". Dupré (2001, p. 1) defines scientism as "an exaggerated and often distorted conception of what science can be expected to do or explain for us". The term can be used both in relation to the role of science in society—as it is here—or ontologically (concerning which questions can be answered by science) (Stenmark 2001). A scientism-based view is often associated with a linear understanding of innovations, that is, a belief that product development follows applied research, which in turn follows the basic research in a linear sequence, rather than that it is a result of knowledge dynamics.

2.2 The Case of Perfluorinated Compounds

In connection with the International Year of Chemistry in 2011 many different applications of chemistry in society were highlighted. In February the theme of the month in Sweden was fashion. In relation to an event called "Fashion & Molecules" the following appeared in a newspaper report:

> "Chemistry has been important to fashion and the fashion industry and is behind success stories such as nylon stockings and the Gore-tex jacket." (Skånska Dagbladet, 13 February 2011; my translation)

Similarly, in a college textbook about chemistry in everyday life (Jakobsson 2003, p. 197), Teflon®—a polyethen polymer where all hydrogen atoms have been replaced with fluorine atoms—is described as "an excellent material for pans" (my translation). Gore-Tex® and Teflon® both contain chemicals belonging to a group of chemicals called perfluorinated compounds (PFCs). Such chemicals are very persistent and some researchers are concerned about their health effects, including increased risk for cancer (see for example: http://pollutioninpeople.org/toxics/pfcs, accessed 24 February 2011). In both the newspaper report and the textbook the fluorinated products are described in an uncritical way. Only the benefits of chemical applications are emphasised, and the risks are not described.

I would claim that many chemistry teachers and chemists have a nonchalant attitude towards the public's fear of chemicals. They think that the public is "chemophobic". The following typical statement is taken from an abstract to an oral presentation held at the 18th International Conference on Chemical Education: "[P]eople blames 'chemicals' for causing some issues such as water quality, air pollution, and herbicides, etc. Although life is made of chemicals and human life cannot sustain […] itself without chemicals, most of [the] public are unaware of the importance of chemicals and chemistry" (Do and Jin 2004). As illustrated in this quotation, chemistry teachers often take an uncritical view of the role of chemistry in society.

2.3 Knowledge Emphasis in Dominant School Chemistry

Students are often uncertain about the aims of chemistry. This is partly due to philosophical difficulties in describing the aims of chemistry (Schummer 1999), and partly due to the fact that several different types of knowledge are emphasised within each teaching unit (Van Berkel et al. 2009). Schummer (1999) points out that "all received concepts to distinguish between science and technology fail, if we try to apply them to chemistry". Furthermore he writes: "From the point of view of philosophy of science, it is extremely difficult to understand what chemistry is all about."

The tension between academic rationalism and social relevance in the science curriculum can be discussed using the seven knowledge emphases set out by Roberts (1998).

These are: Correct Explanations; Solid Foundation; Structure of Science; Self as Explainer; Scientific Skill Development; Everyday Coping; and Science, Technology and Decisions. Van Berkel et al. (2009, pp. 34–35) stress that it is problematic when several of the emphases appear in the same teaching units: “A mixing of emphases leads to confusing messages in chemistry lessons about what should be learned and why […] Making clear and consistent decisions on the curriculum emphasis of units is necessary in order to escape from the existing confusion”. They argue that when the message about what is to be learned is unclear, curriculum designers, teachers and students tend to fall back on the dominant form of chemistry education, which emphasises the Solid Foundation.

It is interesting to pay attention to what is emphasised currently in chemistry teaching. Therefore I below refer to three recently published empirical studies about chemistry teaching in (upper-)secondary schools in Sweden. Maria Kouns (2010) has recently done an extensive empirical study in which she observed 31 chemistry lessons in an upper-secondary school science class. The chemistry teacher was described as “very experienced” and was appreciated by the students. In addition to the many observed lessons, the empirical material included several interviews with both the chemistry teacher and the students and four questionnaires answered by the students. Kouns concluded that the studied chemistry teaching included formal/disciplinary aspects and pragmatic aspects (as described in columns 1 and 2 in Table 1), but not reflective aspects (as described in column 3 in Table 1). Kouns writes (pp. 95–96): “The reflexive domain in which the subject knowledge is questioned and examined from a wider societal perspective is not represented in the material. Connections from chemistry to everyday life and society are instead made in the approach to a content area by how chemistry is applied. Language skills of a more discursive nature are therefore not asked for” (translated by Maria Kouns). One example is when the chemistry teacher begins her lesson by presenting a newspaper article about a fire in a coal mine, but then starts asking about chemistry facts without any reflection on the social context.

In another recent study Eriksson et al. (2011) compared the teaching practices in some secondary school chemistry classrooms in Sweden and Finland. In Finland the chemistry teaching was dominated by knowledge reproduction. In Sweden, on the other hand, the teaching practices were much more divergent, and one of the three studied classrooms was actually dominated by contextualisation. Eriksson et al. characterise the chemistry content in the Finnish classrooms as “chemistry–chemistry” and that in the Swedish classrooms as “socio-oriented chemistry”. The latter is also indicated in a third recent study, which surveyed more than 350 Swedish upper-secondary school students and found that the students think that everyday-life connections are fundamental for school chemistry to be interesting and relevant (Broman et al. 2011).

I think that the described chemistry teaching is very representative. It is commonly like it is in Finland, where mainly formal/disciplinary aspects (the Solid Foundation) of chemistry are dealt with, but it is also quite common that chemistry teachers try to connect the chemical content to everyday life and society. However, this is done from a technical-instrumental perspective and not from a critical perspective, where the chemistry teacher problematises the role of chemistry and chemists in the society, viewing it from different perspectives.

In line with this, Gräber (2002) points out that current chemistry teaching is often too content-focused, with an emphasis on the internal structure of chemistry. He stresses that there is too little STS (=Science, Technology and Society), coupled with local issues, politics and global issues. Similarly, Van Berkel et al. (2009, p. 33) highlight that “student activities in mainstream school chemistry […] do not put emphasis in the curriculum on personal, socio-scientific and ethical questions that are relevant to students' lives and society."

3 Towards an Alternative Discourse in Chemistry Education

As shown in column 3 in Table 1 a reflective and critical discourse of chemistry includes meta-perspectives, problematisation and a *Bildung* orientation. In this section the debate of "science for all" versus "pipeline science" will be described, followed by an introduction to the concept of risk society and its connection to the concept of *Bildung*.

3.1 Chemistry for All Versus Pipeline Chemistry

Aikenhead (2006) contrasts a traditional discipline-oriented view of science education, based on an ideology of preprofessional training of elite students, with science education for all, including humanistic perspectives. He writes: "I find *humanistic* the best word to describe the diverse yet pervasive alternative to the pipeline ideology of traditional school science" (p. 2). Aikenhead emphasises that humanistic perspectives in the science curriculum are not restricted to STS curricula; elsewhere they may be referred to with expressions such as science for public understanding, citizen science, socio-scientific issues, and *Bildung*. These humanistic science perspectives have in common the goal of scientific literacy for all. According to Aikenhead, "a humanistic perspective […] promotes practical utility, human values, and a connectedness with societal events to achieve inclusiveness and a student orientation" (p. 22). Furthermore, he writes: "The issue of relevance is at the heart of humanistic science curricula" (p. 31). Humanistic content includes both the nature of science and the social aspects of science—in other words, knowledge *about* science and scientists.

In the debate of "science for all" versus "pipeline science" Holbrook and Rannikmae (2007) write about "education through science" versus "science through education". Similarly, Roberts (2007) contrasts Vision II of scientific literacy with Vision I. The former is focused on the use of science in society instead of content and research processes, which is the focus of Vision I. Vision II is intended to provide the students/citizens with the science they need, for example, to be critical consumers (McGregor 1999) and to develop health and environmental literacy (Schnack 2008).

The tension between the traditional/dominant and the humanistic approaches is also discussed in the field of Chemistry Education. Gilbert and Treagust (2009a) contrast Group A and Group B chemistry curricula. The Group A chemistry curriculum aims at "chemical literacy" and focuses on the following knowledge emphases: Everyday Coping; Self as Explainer; and Chemistry, Technology and Decisions. The Group B chemistry curriculum, on the other hand, is for those students that will continue with chemistry at an advanced level. Van Berkel et al. (2009, p. 44) writes: "Chemistry for citizenship […] differs from mainstream school chemistry regarding the aims for future chemical education." What is important is not the reproduction of facts and algorithms, but that the knowledge connects to daily life and societal issues.

Pedretti et al. (2008, p. 955) point out that what they call STSE education (where E stands for Environment) "represents a post-positivist vision of science and science teaching that emphasizes: transformation (through sociopolitical action); decision-making; interdisciplinarity; uncertainty; multiple solutions; the coupling of science and ethics; and teacher as facilitator and guide". Why there has been so much resistance to this form of humanistic science/chemistry education in practice is discussed in a recent paper by Bryce (2010). He contrasts the dominant *Science-for-scientists* view (emphasising content) with *Science-for-citizenship* (emphasising the contextual complexities currently facing citizens in the modern society).

3.2 Risk Society and the Need for *Bildung*

Sociologists argue that we live in a risk society, characterised by increasing complexity and unpredictable consequences of techno-scientific innovations and production (Beck 1992; Ekberg 2007). One example is the "chemicalisation" of the society (Casper 2003), which can be regarded as a "megarisk".

The risk society needs educated citizens who are able to understand the world and make informed decisions (Jensen and Schnack 2006; Schnack 2008), in both their private and professional lives, and as citizens engaged in democratic processes. Mogensen and Schnack (2010, p. 60) argue that "action competence is closely linked to democratic, political education and to […] the notion of '*Bildung*'".

Baumann (1991) stresses that citizens in the risk society need to learn to live with ambivalence. There is a need for what Norris (1997) calls "epistemic distance", which means a balance between modernism (and scientism in its extreme form) and scepticism. Elam and Bertilsson (2003, p. 239) describe the two sides with reference to the "unnecessary arrogance and over-assuredness of some scientists" and the "ignorant and over-emotional attitudes of some publics", respectively. Stafford (2006), who connects this critical balance to practical wisdom, writes: "Practical wisdom […] includes the ability to know as well as doubt, and to find a balance between the two that avoids the extremes of too confident knowing and paralyzing doubt."

For Elmose and Roth (2005, p. 21), who discuss citizen competences needed in the risk society, *Bildung* "involves competences for self-determination, constructive participation in society, and solidarity towards persons limited in the competence of self-determination and participation". They refer to the German scholar Wolfgang Klafki (2005) and his concept of *(Allgemein)bildung*. In this paper I use *Bildung* in a similar way as Klafki—*Bildung* as a democratic task.

Elmose and Roth (2005) ask three important questions concerning needed competences in the risk society. Here these questions are asked in relation to chemistry: (1) What are the [chemical] competences required in a risk society?, (2) How do young people acquire the required [chemical] competences?, and (3) What competences do [chemistry] teachers need to prepare students for risk society? There will not be room to give detailed answers to these questions in this paper, but they will be addressed briefly. However, prior to that I will give an introduction to Johnstone's chemical triangle and discuss my suggestion for a subdivison of "the human element" of Mahaffy's tetrahedron.

4 Human Elements in Chemistry Education

Thirty years have passed since Alex Johnstone (1982) described the content in chemistry teaching with a triangle (see Fig. 1), which became known as the chemistry triplet or Johnstone's triangle. Recently, Gilbert and Treagust (2009b, p. 6) suggested that the triplet should be called the "triplet relationship". It consists of three corners representing the formal aspects of chemistry: *the macro level* (e.g. substances and properties), *the submicro level* (e.g. atoms and molecules), and *the symbolic level* (e.g. symbols and equations). In

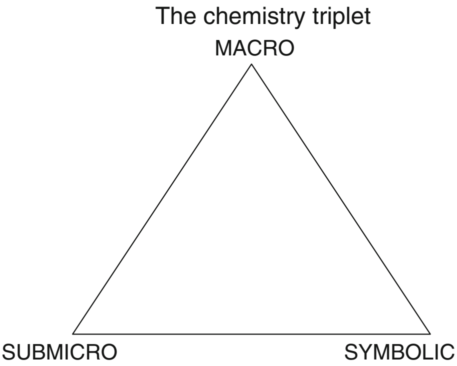

Fig. 1 Johnstone's *triangle* with the corners representing the formal aspects of chemistry education: *the macro level* (e.g. substances and properties), *the submicro level* (e.g. atoms and molecules), and *the symbolic level* (e.g. symbols and equations)

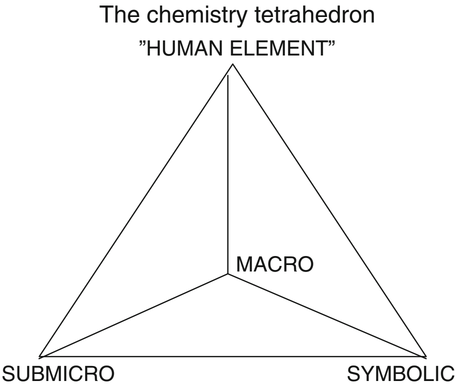

Fig. 2 Mahaffy's (2004) *tetrahedron*, which complements Johnstone's *triangle* with a *top*, representing the human element in chemistry teaching

the research area of Chemistry Education the triplet relationship is now well established (Jong and Taber 2007, p. 632; Barke et al. 2009, p. 27; Gilbert and Treagust 2009c; Talanquer 2011) and it has also recently been reprinted in one of the world's leading textbooks in physical chemistry, *Chemical Principles* (Atkins and Jones 2008, p. F3).

The triplet relationship raises several difficulties for chemistry students, such as difficulties to move between the different levels, misconceptions about the submicro level and the low degree of practical experience with chemical reactions at the macro level (Gilbert and Treagust 2009a). When analysing the chemistry triplet from a discourse perspective (as discussed above), labels such as objectivism, reductionism and rationalism—and maybe also positivism—are useful.

In 2004 Peter Mahaffy (2004) suggested that the "chemical triangle" should be complemented with a "human element" as a top of a tetrahedron (see Fig. 2). The top then represents a human context in chemistry teaching. With this, Mahaffy suggests both that more emphasis should be put on the everyday-life and societal aspects of chemistry, and that chemical learning processes should be in focus, for example, by using student-active approaches and by using the research literature on learning in chemistry when planning and designing chemistry teaching. Barke et al. (2009, p. 32) have further complemented the tetrahedron with Vygotsky's "Zone of Proximal Development" (ZPD) and a "Pedagogical-Content Knowledge" (PCK) metaphor. They call it Content-Pedagogy-Context-Research Knowledge, where content knowledge stands for chemistry content knowledge according to the chemistry triplet, pedagogical knowledge for an understanding of

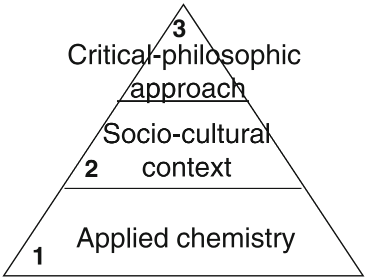

Fig. 3 Subdivision of the top (the "human element") of the chemistry tetrahedron. The bottom triangle (not seen in this figure) is about learning pure chemistry, *Level 1* about learning applied chemistry, *Level 2* about learning *about* chemistry, and *Level 3* about philosophical reflection and socio-political action concerning chemistry

chemical teaching and learning, contextual knowledge for placing the chemistry content knowledge in STS contexts, and research knowledge for evidence-based chemical teaching (for a further discussion, see the concluding remarks).

In this paper the tetrahedron model is developed further. The human element, at the top of the tetrahedron, is subdivided into three levels: (1) applied chemistry, (2) socio-cultural context, and (3) critical-philosophic approach (see Fig. 3). The three levels are related to the following major components of the science curriculum, as discussed by Hodson (2003): (1) Learning Science and Technology, (2) Learning About Science and Technology, and (3) Engaging in Socio-political Action. They are also related to the following five (of a total of eleven) identified explanations of "scientific literacy" by Norris and Philips (2003):

1. Knowledge about the substantive content of science; Understanding science and its applications
2. Understanding the nature of science, including its relationship with culture
3. Knowledge about the risks and benefits of science; Ability to think critically about science

Below, the three levels of the human element are discussed further.

4.1 Level 1: Applied Chemistry

The most science-related form of bringing everyday-life and societal aspects into chemistry teaching is by using applications as examples (De Vos et al. 2002). These could be chemical phenomena in everyday life, consumer products, and different applications of chemistry in the areas of health and/or the environment. Also teaching related to business and chemical research, when it is done from a technical-instrumental perspective and not from humanistic and/or critical perspectives, should be placed in this category. An example of industry emphasis, rather than emphasis on "citizen chemistry", is the following quotation from the chemistry educator Wallace (2003, p. 90): "We must turn […] to the needs of the ultimate consumers of universities' products: industry and commerce." Similarly, Ware (2001) argues in favour of teaching chemistry from a societal perspective, but it is from a quite modernistic point of view. Actually, I would assert that Mahaffy's (2004) perspective, when he suggests a human element in future chemistry education, is also of this kind.

Previously I described the chemistry teaching studied by Kouns (2010). The teaching was characterised by a focus on core chemical content (knowledge emphasis on the Correct

Explanations and Solid Foundation), but also by some examples from media and everyday life, either as interesting starters or presented at the end of lessons to show how the chemical concepts can be applied. However, these societal connections were made within what Aikenhead (2006, p. 3) has called “a trivial everyday context” and/or only from technical-instrumental perspectives. When analysing the “applied chemistry” level in the chemistry tetrahedron from a discourse perspective (as discussed above), labels such as modernism—and maybe also scientism—are useful.

National chemistry curricula in three Nordic countries (including Sweden) have been analysed and compared by Vesterinen et al. (2009). They conclude that all the studied curricula “define the role of chemistry in society on the instrumental level—as a tool to produce new applications” (p. 207). Chemical technology is presented “as almost exclusively beneficial for human beings. It is seen as a way to support sustainable development and to enhance living conditions” (p. 208). The latter is typical of what is often called “ecological modernism” (Jamison 2001). Based on the curriculum analysis by Vesterinen et al. (2009), it is easy to understand the background of current Swedish chemistry teaching, as described by Kouns (2010) and Eriksson, Ståhle and Lindberg (2011).

Gilbert (2006) has discussed four models of context in chemical education (see further below). The first model, which he states actually does not meet the criteria for a context-based curriculum, he calls “Context as the direct application of concepts”. About this model he writes: “This approach often seems to infer one-directional and rigid relationships between ‘concepts’ and ‘applications’” (p. 966), suggesting a linear understanding of innovations, which is often associated with scientism. As discussed above, I would stress that this type of “contextualising” is typical of much contemporary chemistry teaching.

4.2 Level 2: Socio-Cultural Context

Gilbert’s (2006) other three (of four) models of context in chemical education are:

(2) Context as a reciprocity between concepts and applications (i.e., the meaning of concepts depends on the social context). Gilbert states that this model is better than model one (discussed above), but it is not obvious to students why they should learn/use chemistry for dealing with certain problems.

(3) Context as provided by personal mental activity

(4) Context as the social circumstances

The last model, which Gilbert (2006) regards as the best one, is based on situated learning and activity theory. He writes: “The task form […] must include problems that are clear exemplifications of chemically important concepts, to enable learners to develop a coherent use of specific chemical language” (p. 970).

The second level in the tetrahedron (see Fig. 3) is called “socio-cultural context” and is about systemic knowledge of chemistry. Socio-cultural context refers to historical, sociological, cultural and political perspectives or, in one word: *socio-chemistry*. This word was also recently used by Cullen (2008) to describe the interface and interactions between chemistry and society. A related (although broader) word is “meta-chemistry”, which covers philosophy of chemistry, chemistry education, history of chemistry, “chemistry and society”, and green chemistry (Sjöström 2006). Similarly, Ziman (2001) has argued for “meta-science”, a discipline that extends beyond conventional philosophy and includes social and humanistic aspects of the scientific enterprise.

As mentioned earlier, Van Aalsvoort (2004, p. 1151) has shown that “logical positivism causes chemistry’s lack of relevance in chemical education”. Just like Van Aalsvoort, Brandt (2003, p. 342) argues for chemistry beyond positivism. He writes: "Going beyond positivism […] means connecting to the wider cultural context, the realm of values, meanings, and purpose, and being concerned, more than before, for example about the image of chemistry, the challenges chemists face as citizens, and the problems and opportunities chemists may find in liberal education." According to Tsaparlis (2009, p. 116), "[s]tudents with post-positivist NOS [=Nature of Science] beliefs do not see science as a fixed collection of facts, but allow for compromises and errors, leaving room for changes and developments." Meijer et al. (2009, p. 195) state that by "[s]tarting from the philosophy that chemistry should be considered as a human activity, scientific and technological developments are interrelated with issues in society and part of our cultures."

To summarise, chemistry teaching that can be placed in Level 2 in the tetrahedron concerns learning *about* chemistry, in addition to learning pure chemistry (the chemistry triplet in the bottom of the tetrahedron) and about its applications (Level 1 in the tetrahedron).

4.3 Level 3: Critical-Philosophic Approach

In addition to socio-cultural perspectives and context—Level 2 in the tetrahedron—and what is under this level, *Bildung*-oriented chemistry education should also include a critical approach, aiming at philosophical reflection and socio-political action concerning chemistry. The intention with the latter is, as Hodson (2003) states, "to produce activists: people who will fight for what is right, good and just; people who will work to re-fashion society along more socially-just lines; people who will work vigorously in the best interest of the biosphere". The ideal is that what is good and right should be decided by the action-competent citizens, with *Bildung*.

The mathematics educator Ole Skovsmose (2001, p. 131) has written that a "critical subject is also a reflecting subject". Here I will mention some aspects of a critical approach in chemistry education. According to Skovsmose (2001, p. 123), a critical [chemistry] education—when replacing "mathematics" with "chemistry"—"includes a concern for developing [chemistry] education in support of democracy, implying that the micro-society of the [chemistry] classroom must also show aspects of democracy. […] [Chemistry] itself is a topic which needs to be reflected upon […] Making a critique of [chemistry] as part of [chemistry] education is a concern of critical [chemistry] education." Critical chemistry education should concern ethical aspects of chemistry, risks and uncertainties; it is about assessing, balancing and valuing benefits and risks.

5 Implications

5.1 Implications for the Field of Chemistry Education

To become more critical, I think that the field of Chemistry Education should be informed and guided by recent developments in the field of Environmental Education, which is part of the even broader field of Education for Sustainable Development (ESD) (Schnack 2008). One researcher who has tried to marry Chemistry Education and Environmental Education is Uri Zoller (2004), who asserts that more holistic chemistry teaching would develop high-order cognitive skills, such as analysing, assessing and applying, among the students.

In a paper about sustainable chemistry Böschen et al. (2003) argue that uncertainty and ignorance should be treated more explicitly in chemical research and education. However, this would have consequences for the views currently held by many chemists and chemistry teachers. Böschen et al. write: “Establishing a more explicit and mutual relationship between scientific work and societal needs and values requires the epistemological assumptions of chemistry as a natural science to be rethought because, traditionally, the natural sciences do not have ‘interfaces’ for this kind of interaction with stakeholder groups and for reconciling non-scientific, for example ethical, values and scientific objectives” (p. 94).

Van Berkel et al. (2009, p. 44) discuss the consequences for chemistry teaching and state that “when school chemistry is to address daily-life and societal issues, the curriculum’s philosophy can no longer be ‘objective’ without acknowledging that chemistry is embedded within human cultures and their societies”. It is about ethical and political approaches, as already discussed, but also about risk assessment. Similarly, Christensen (2009, p. 208) thinks that: “School science […] has rarely acknowledged the uncertain dimensions of science […]. It is in relation to decision making, where scientific knowledge is uncertain, that risk understanding can make a significant contribution.” Kolstø (2006, p. 1712) writes: “[S]cience education has an important role in developing students’ understanding of the concepts of risk and uncertainty, and characteristics of research on risk-related issues.”

From a post-modern and deliberative perspective on risks, the society cannot leave it to the experts to deal with risks; people in all parts of society must be involved. According to Christensen (2009), risk education has two challenges: (1) to work more with knowledge uncertainties, and (2) to work with both faces of science—the good and the bad. To meet these challenges, I think, in line with Roth et al. (1996), that the field of Chemistry Education should also be informed and guided by the research field of Science and Technology Studies (STS), and by the related field of Public Understanding of Science (PUS).

According to Turner (2008), the field of Science Education (in which Chemistry Education is a part) is generally not very aware of the PUS field. By analysing the concept of “scientific literacy” and how it has developed historically, and comparing it to the development of the PUS concept, he concludes that the view of “scientific literacy” is more modern in the field of Science Education and more post-modern in the field of PUS. However, especially during the 1980 s, there were three programs or movements in the field of Science Education for incorporating NOS aspects in the science curriculum. These were: (1) history and philosophy of science, (2) “authentic science”, and (3) the STS movement. The ambition of the latter was “to prepare students for enlightened citizenship-participation in the democratic debates about risks and benefits that are essential to the management of a technocratic society” (pp. 58–59).

5.2 Implications for Chemistry Teaching

How should chemistry teaching be organised to support the development of “practical wisdom” and *Bildung*? Aikenhead (2003, p. 125) thinks that chemistry instruction must go from “an uncritical adulation of science (scientism)” to “a healthy scepticism open to critically evaluating modern science and technology”. To become both “critical consumers” and “responsible citizens”, chemistry students need to work with socio-chemical issues in the teaching, where they learn “weighing arguments pro and contra” (De Vos et al. 2002, p. 112). Over the years some different educational designs concerning socio-chemical issues have been developed, for example about chemicals, health and environment (Cross and Price 1992; Bulte et al. 2002; Koker 2007; Marks and Eilks 2009).

More generally Hofstein et al. (2011) have recently reviewed the area of socio-scientific issue (SSI)-based teaching and its importance for contemporary science education. Apart from dealing with opportunities and obstacles when it comes to implementation, they also discuss the choice of social context for shaping "well-informed and critical citizens via science education". They justify more SSI in science education by—just like Elmose and Roth (2005)—referring to the *Bildung* theorist Klafki (2005). Development of *Bildung* can be supported both through action-oriented learning, inspired by Dewey's educational philosophy and through deliberative pedagogy (Englund 2000). Actually, the German term *Bildung* was used in Dewey's work, although understandably not systematically (Bauer 2003).

Marks and Eilks (2009) have recently described principles of socio-critical and *Bildung*-oriented chemistry teaching. They suggest a problem-oriented approach and argue—in line with the position taken in this paper—that context-based chemical education should go beyond applications and superficial daily-life connections. They write: "STS-oriented chemistry lessons [should] include reflective overview of chemistry, its industrial applications and its ecological and socioeconomic impacts" (p. 233). Marks and Eilks have shown empirically that daily life contexts didn't automatically generate motivated students: "[I]t seems that chemistry topics must include more than contexts (even if they stem from everyday-life) in order to motivate student science learning and stimulate pupils' interest and critical skill building" (p. 240). Their successful lesson plans start with current, authentic and controversial problems being debated in the public debate. Examples include issues concerning biofuels, synthetic musk fragrances in soaps, and light-crisps (Marks and Eilks 2009, 2010; Marks et al. 2008).

Paulsen (2006) states that a "*Bildung*-oriented critical-democratic science education" (my translation) should be based on project-, problem- and context-based approaches. Kolstø (2006) stresses that there is a need for mechanisms to ensure that students are confronted with relevant and pluralistic information about the issues. To avoid the risk of curriculum overload, Elmose and Roth (2005, p. 23) argue for exemplary teaching, by which they mean "that the theme of teaching and the theory and methods integrated in the theme are valid beyond the situation itself."

5.3 Implications for Chemistry Teacher Education

With a *Bildung*-oriented approach to chemistry teaching—focusing not only on the scientific discipline called chemistry, but also on other facets (De Vos et al. 2002)—the professional identity of the chemistry teacher is as much that of "meta-chemist" as it is of a "chemist". Aikenhead (2003, p. 125) writes: "One major challenge for chemistry […] teachers is to rethink and reformulate their professional identities away from being loyal and accountable to their discipline."

What then would characterise chemistry teacher education that emphasises *Bildung*-oriented chemistry? Two main perspectives that should complement the subject focus in dominant chemistry education are "chemistry as culture" and "chemistry within culture". Krageskov Eriksen (2002) argues in favour of the need for three kinds of knowledge in chemistry education (including chemistry teacher education): (1) "ontological" chemical knowledge (i.e., real chemistry), (2) "epistemological" knowledge (i.e., philosophical and sociological perspectives on the chemical practice), and (3) "ethical" knowledge (i.e., problematisation of the role of chemistry in society). All three kinds of knowledge are needed in the education of reflecting citizens with *Bildung*, and therefore also in the education of chemistry teachers. Krageskov Eriksen writes: "[I]f a *Bildung* focus […] is adapted as a perspective on education, the awareness of all three spheres of chemical knowledge must be raised to explicate and open the 'rules of the chemistry game' for reflection and debate."

Recently, Maja Aksela (2010) at the University of Helsinki in Finland described their evidence-based chemistry teacher education, stressing inquiry-based learning. One of the mentioned key areas of knowledge needed by chemistry teachers is "understanding the nature of chemistry and scientific inquiry" and one of the courses in Helsinki is called "Chemistry as a science and a discipline". However, there does not seem to be any course dealing with critical perspectives on the role of chemistry in society. In the same way as the field of Philosophy of Chemistry has an important role in chemistry teacher education (Erduran et al. 2007), the fields of Science and Technology Studies, and Environmental Education, respectively, would have important roles.

6 Concluding Remarks

To summarise, critical and *Bildung*-oriented chemistry education is about problematisation, understanding uncertainties, and balancing the benefits and risks of chemistry; it deals with ethical and societal aspects in the teaching. With this type of chemistry education, chemistry teachers—in addition to extensive content knowledge *in* chemistry—also need extensive knowledge *about* chemistry (meta-perspectives). Furthermore, they need to develop a professional identity which differs from the identity of chemists. The reflecting chemistry teacher takes a critical-philosophic approach to chemistry—both regarding problematisation of the triplet relationship and regarding ethical aspects of chemistry in society.

Bildung-oriented chemistry teaching should be based on the "Pedagogy-Content-Context-Research Knowledge" model suggested by Barke et al. (2009), complemented by a critical approach to chemistry. In this paper I have suggested a tetrahedron based on Johnstone's (1982) triangle and with Mahaffy's (2004) top, where the latter—in addition to chemical engineering and other applications (Level 1) and socio-cultural-historical context (Level 2)—also contains a critical-philosophic approach (Level 3; reflective elements). Unlike the dominant, traditional chemistry teaching, which focuses on formal (disciplinary) aspects and at best also includes Level 1 (with pragmatic and often trivial everyday-life aspects), *Bildung*-oriented chemistry teaching also includes "meta-perspectives" and systemic knowledge (Level 2) and a subject-critical distance (Level 3).

More meta-perspectives (philosophical, historical and socio-cultural) within chemistry education practice would probably improve the currently too rationalistic and reductionistic image of chemistry. Chemistry teacher education and also the chemistry classrooms would then become more welcoming for those from a broad spectrum of personal backgrounds and ideologies.

I will conclude by quoting two recent articles concerning what I have been calling *Bildung*-oriented science/chemistry education:

> "[S]cience education that addresses contemporary socioscientific issues (in which risk is likely to be encountered) is concerned with the goal of citizenship. This sets science in its sociocultural context and an integrated conception of risk, including scientific, personal and sociocultural dimensions, would seem appropriate." (Christensen 2009, p. 214)

> "[T]he initiation into normal chemistry should be largely replaced by an education in or through fluid, critical and creative chemistry, together with an education in or about the relations between chemistry, technology, and society." (Van Berkel et al. 2009, p. 47)

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