Teaching and Learning for Critical Scientific Literacy: Communicating Knowledge Uncertainties, Actors Interplay and Various Discourses about Chemicals

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The modern society can be described as a globalized risk society characterised by increasing complexity and unpredictable consequences of techno-scientific innovations and production. One example is the "chemicalisation" of our society, bodies and nature. In order to manage this, society needs educated citizens who are able to understand the complexity of the world and make value-based decisions – in both their private and professional lives. For example critical-democratic citizens – with "Bildung" – are able to value information about environmental chemicals and chemical risks. One arena with great potential for enabling critical-democratic citizenship is education. This chapter describes and problematizes teaching and learning about risk-related chemicals, such as additives, contaminants, pollution and various environmental chemicals. Such socio-chemical issues is a type of socio-scientific issues (SSI). Chemicals Education is suggested to be based on a "chemicals education triangle", with the following three corners: (1) the nature of chemical risks, (2) the interplay between actors in "the chemical society", and (3) pluralism and awareness regarding various "chemical discourses". The communication inside and outside the science/chemistry classroom about the interplay between chemistry and society can be analyzed and discussed based on such a triangle.

Critical-democratic citizens need "chemicals *Bildung*"

Chemical risks have entered the scene of mass media and popular culture. For example, early in 2013 media reported on the WHO-report "State of the Science of Endocrine Disrupting Chemicals". The conclusion of the report was that the link between endocrine-disrupting chemicals and many diseases, like cancer and diabetes, is even stronger than has previously been thought (Vandenberg, 2012). This example is only one in a series of chemical alarms in recent years; others being e.g. plasticizers like phtalates and bisphenol A in baby bottles. Furthermore, several popular books and movies have been released. Examples include the books "Slow death by rubber duck: How the toxic chemistry of everyday life affects our health" (Smith & Laurie, 2009) and "Power, plastics, toxic chemicals and our children" (Forsberg, 2014; our translation), and Stefan Jarl's documentary in Swedish from 2010 (available with English subtitles), "*Underkastelsen*/Submission" about "*the*

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chemical society". The message of all these is that chemicals that are threating health and environment must be taken at least as serious as the threat of climate change.

The so-called chemical society is part of the "risk society" (Beck, 1992; Ekberg, 2007), in which citizens must be able to manage health and environmental risks of which scientific knowledge is one of several necessary knowledge bases (Elmose & Roth, 2005). In line with this pluralistic view of the knowledge skills required to manage risks, science education must be designed with the purpose of educating critical-democratic citizens (Aikenhead, 2006; Hodson, 2011; Hofstein, Eilks & Bybee, 2011; Sjöström, 2013). Hodson (2011) argues for a critical scientific, technological and environmental literacy, shortened to *critical scientific literacy*. The thinking and acting of autonomous, critical thinking and ethically-aware citizens is related to the concepts of critical citizenship (Johnson & Morris, 2010) and *Bildung*.

Bildung is the German term for a key idea in the continental European educational tradition. According to Schultz (2009, p. 228) it has "influenced educational ideas and curriculum in Germany, Central Europe and Scandinavia". Because there is no precise English translation, the German term is used in the international educational literature. According to Wimmer (2003, p. 185) "*Bildung denotes whatever is not covered by the other central concepts of pedagogical theory such as socialisation, education, and instruction*"; it stands for them all and also something more. It is, according to him, "*the central critical concept of modern pedagogy*". Due to its both educational and political dimensions "*it allows us to say something different about education*" (Biesta, 2002, p. 344). For Elmose and Roth (2005, p. 21), who discussed 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*".

According to Biesta (2012a, p. 817) "*the role of the individual in the process of* Bildung, […] *has to be understood as a* reflexive *process*", i.e., a process were the individual establishes both a relationship and a critical stance towards the existing culture and society. In this process of "subjectification" the individuals become "*autonomous – subjects of action and responsibility*" (Biesta, 2012b, p. 7). This phrase "*tries to capture a conception of human subjectivity that is not selfish or self-centered but always understood as being in responsible relation with other human beings and, by extension, with the natural world more generally*" (Biesta, 2013, p. 739). Biesta (2012b, p. 16) describes this as "*highly political, as it intervenes in and reconfigures the existing order of things*".

One arena with great potential for enabling critical-democratic citizenship is education. Mogensen and Schnack (2010, p. 60) have argued that their concept *action competence* is "*closely linked to democratic, political education and to […] the notion of 'Bildung'*". So called critical pedagogy is driven by a concern for socio-ecojustice (Cho, 2010; Johnson & Morris, 2010; Mueller, 2009; Santos, 2009). Its focus is on the relationship between knowledge and power and its agenda is transformation of knowledge (e.g. curriculum) and pedagogy (e.g. teaching).

To specify the meaning with *Bildung* today, we have to make a *diagnosis* of our time, which can be a globalised risk society with many ecological challenges (Biesta, 2002). Albe (2013) emphasizes that "*environmental emergencies and the close interrelationships between technoscience, economics and social transformations constitute key drivers for rethinking our culture and, more specifically, the aims, strategies and content of science education*" (p. 188). There needs to be "*a shift from subject matter content to socio-educative aims and socio-political actions*" (p. 185).

Except for scientific concepts and models, which is in focus in traditional science/chemistry teaching, scientific processes and societal contexts should also be emphasised in socio-critical, *Bildung*-oriented and *humanized* science/chemistry education (Sjöström, 2013; Sjöström & Talanquer, 2014). In practice it would mean including more ethical and socio-political perspectives in the teaching, and the focus would be on problematisation, understanding uncertainties, and balancing the benefits and risks of science. According to Christensen (2009) risk education has two challenges: (1) to work more with knowledge uncertainties, and (2) to work with both sides of science – the good and the bad, i.e. science as Janus-faced. The aim of critical scientific literacy is to have knowledge and abilities for being an autonomous, responsible-taking and action-competent citizen, working in the interest of socio-ecojustice and global sustainability (Hodson, 2011).

Introduction of the "Chemicals Education Triangle"

Eilks and others have discussed principles of socio-critical science/chemistry teaching (Eilks, Rauch, Ralle & Hofstein, 2013; Marks & Eilks, 2009). Their evidence-based lesson plans start with current, authentic and controversial problems present in the public debate. Among other elements a case includes scientific/chemistry content knowledge, experiments and argumentation. Especially one of their cases, synthetic musk fragrances in shower gels, is connected to the chemicalisation of our society and bodies (Marks & Eilks, 2010). Other useful cases could be issues concerning plastics (Burmeister & Eilks, 2012) or nanotechnology (Jones et al., 2013). The more general term for the type of teaching suggested by, e.g., Eilks et al. is socio-scientific issues (SSI) education (Sadler, 2011). *Socio-chemical issues* (SCI) (Sjöström, 2013) is a good example of SSI and *Chemicals Education*, the name we here use for teaching and learning about SCI, is part of what can be called sustainability-driven science/chemistry education. Chemistry education for sustainability should be e.g. interdisciplinary, holistic and value-driven, promote critical thinking (in a broad sense), and involve participatory decision making (Burmeister, Rauch & Eilks, 2012; Sjöström, Rauch & Eilks, in press).

This chapter discusses how science/chemistry education can be developed to be even more oriented towards critical-democratic citizenship and *Bildung*. Below we introduce a *Chemicals Education Triangle* (see Figure 1), where the three corners are chemical risks, the chemical society, and chemical discourses, respectively. From such a triangle it is possible to discuss how for example the interplay between chemistry and society can be communicated in the classroom (our focus here), but also elsewhere, such as in the media, which is the public's main source of information regarding chemical risk issues (Stenborg, 2013).

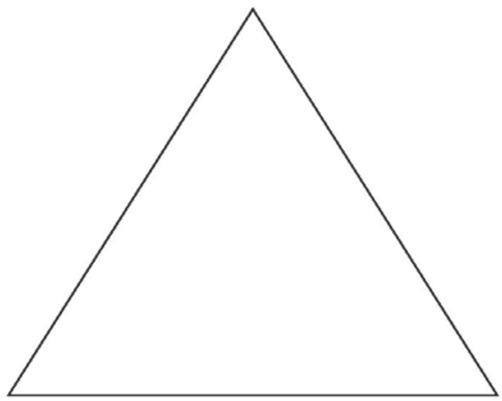

Figure 1. Chemicals Education Triangle

The three core ideas of *Chemicals Education* correspond to the corners in the triangle. They can briefly be described with the following questions:

1. *Chemical risks*: What do we mean with the term "chemicals"? What do we mean with the term "risk"? How do chemicals influence health and the environment? What do we know about chemical risks? What knowledge gaps and uncertainties are there in research?
2. *Chemical society*: How has the chemical society emerged? What are its actors and characteristics? What role has law and citizens in the chemical society? Which (greener) alternatives are there?
3. *Chemical discourses*: What is meant with "chemical risks"? Which emphases and values are expressed? Who is speaking (and based on which values)? Is the communication pluralistic?

Corner one: (Un)knowledge about chemical risks

This corner problematises the scientific (and also public) knowledge about "chemical risks". The problematisation has two roots – "chemicals" and "risk". First, we need to start discussing what the term "chemicals" stands for. The term is used in at least three ways: (1) In media and everyday language chemicals is synonymous with hazardous chemical substances, i.e., something poisonous; (2) natural scientists and chemists generally claim that everything material consist of chemicals. For example the Nobel Laureate in Chemistry in 1981, Roald Hoffman (1995, p. xiv) has written: "*So are you, and I – chemicals, simple and complex*". (3) A third and stricter definition of the term is "a chemical product [commercially used chemical substance or mixture of several chemical substances] which is macroscopically homogeneous" (Martin, 2001; our translation).

Chemical substances, or chemicals in the broad sense of the term, can be subdivided into those that are occurring in nature and those that are synthesized by man. The synthetic substances can in turn be subdivided into those identical to natural once and those that are artificial/unnatural. It is usually the latter category that is colloquially referred to as “chemicals” (Kraus, Malmfors ‘& Sloric, 1992; Bretz & Emenike, 2012). The public perception is generally that natural substances are less harmful to health and environment. These are different from synthetic substances, which the public see as synonymous to chemicals and something artificial and harmful (Dickson-Spillmann, Siegrist & Keller, 2011).

The core of our use of the term is in line with definition one above and to synthetic chemicals, but our aim is to broaden the concept to enable various and therefore more nuanced understanding of chemicals and chemical risks (to also include the benefits of chemicals).

To understand when chemicals pose a risk from a scientific point of view, it is important to distinguish between risk/danger, uncertainty, and ignorance (EEA, 2001, pp. 192). For risk/danger the cause-effect-relationships is enough known to be able to estimate the probability for an undesirable effect to occur. When there is an uncertainty, many factors are known, but not enough to safely estimate the probability, e.g. the relationships between many CMR substances, i.e. substances classified as carcinogenic, mutagenic and/or toxic for reproduction, and their consequences for health and the environment. Rudén (2004) writes:

> *There is in practice always uncertainty inherent in toxicological and analytical data. The uncertainty exists both at the primary level, i.e. scientific uncertainty inherent in the scientific methods, and at the level of the risk assessment, i.e. in the extrapolation and interpretation of, sometimes conflicting, data. (p. 344)*

At the level of ignorance the potential risks are not yet known. For chemicals there are often knowledge uncertainty; many risk factors are known, but not cause-effect relationships. This is typical for the so-called “cocktail effect”, i.e. the combined effect of all the chemicals that we are exposed to in our daily life. However, there are also knowledge uncertainties concerning many chemical’s properties. Ecosystems and living organisms are so complex that there will always be a high degree of uncertainty about the adverse effects from most synthetically produced and distributed chemicals. This becomes particularly clear as it is estimated that approximately 100 000 chemicals are used commercially, of which only a small part has been carefully evaluated (Brown, 2003; Karlsson, 2010). There is thus, *de facto,* a very large lack of knowledge regarding chemicals in use in society.

Corner two: The emergence and characteristics of the chemical society

This corner problematises what the massive increase in the use of chemicals implies. Since the mid 19th century and especially since WWII there has been an enormous *chemicalisation* of the society, with both positive and negative consequences (Stenborg, 2013). Hillmo (1994) writes:

> *This term covers both quantitative changes of the use of chemicals, as well as qualitative, because chemicalisation is not only about chemical substances; it also intervened in a further structural change in a number of areas of society. This*

> *transformation could be summarized as an introduction, utilization and dissemination to most areas of society of what in a broad sense may be termed chemical engineering. (p. 278; our translation)*

As indicated above, the modern society can be described as a globalized risk society, characterised by increasing complexity and unpredictable consequences of techno-scientific innovations and production. But science and technology is also needed to identify, examine and understand the risk issues at hand. The chemicalisation of our society and bodies (Casper, 2003) is only one example. According to Beck (1992) the risk society needs a reflexive modernity, with critical-reflexive citizens, a vivid public debate, a problematisation of science/technology and green technology in order to manage risks.

During the last decades there has been a greening of the chemical sector (Sjöström, 2006; Sjöström, Rauch & Eilks, in press). Two examples are the Green Chemistry-movement (Linthorst, 2010) and REACH – the chemicals legislation of the EU. However, many of the mechanisms of the chemicalisation of society are still there. Except actual unknowledge about chemical risks (corner one of the triangle), the globalized economy with long product chains, make knowledge transfer of chemical risk very difficult (Fransson, 2012; Stenborg, 2013).

A characteristic of the chemical society is the tension between and the co-existence of benefits and risks. From a benefit-perspective the use of chemicals is characterized by that the properties are obvious, well-known and desired. It is easy to see the economic benefits, but this effect is usually relatively short-lived. From a risk perspective, the use of chemicals is characterized by uncertainty, especially regarding effects on health and environment. Furthermore, the effect is often chronic and irreversible, and it is therefore very difficult to estimate the real economic cost of using synthetic chemicals in society (EEA, 1999, p. 22).

Some other characteristics of the chemical society are the many (new) chemicals that are made by humans and used in large scale in society (Karlsson, 2010), the high cost of finding out a chemical's toxicity (Rudén, 2004) and the many small and diffuse levels of a variety of problematic chemicals that can be found in a wide range of consumer products (Stenborg, 2013).

An effect of the characteristics above is that risks must be defined collectively in society. As is always the case for SSIs, it is about interpretation and evaluation, both at individual and societal levels (see e.g. Macgill & Siu, 2005 or Taylor-Gooby & Zinn, 2006). Various actors such as companies, governmental agencies and NGOs will come to different conclusions regarding risks. The reason is the ethical, political and economic value conflicts caused by different views on how society should manage chemical risks. Weighted risk assessments, which are based on facts, but also on values, is about tradeoffs between desirable features of chemicals, on one hand, and on a more or less extensive safety ambition, on the other hand. The various actors in the chemical society will use different chemical discourses (see further corner three of the triangle).

Corner three: Various chemical discourses

The public gets most of its information about risks from media. Risk framings in media are stable and collective (Van Gorp, 2007), and based on general and widespread cultural interpretative schemes. Recently, Stenborg (2013) discussed different framings in media concerning chemical risks of consumer goods. She showed that the framing of a risk topic is highly contextual, depending on for example which chemical or product group is in focus and who is at risk. Framings of risks thus include both scientific and other perspectives (Tewksbury & Scheufele, 2008). For example are “the market” and references to “common knowledge” of risks or of chemicals often present.

It is important to show respect for the public’s fear, values and choices when it comes to chemical risk. The use of both phthalates and bisphenol A has been restricted during the last years. In both these cases the restriction originated from the public’s reaction, and it was not until later that the scientific evaluation proved the public right.

However, many chemists have sometimes a nonchalant attitude to the public’s fear of chemicals (see e.g. Gribble, 2013). As an example, some years ago the Director of the Swedish Plastics & Chemicals Federation wrote:

> *The human being consists of many different ‘chemical factories’ and chemical processes go on continuously as part of our daily life. […] Basically there is no difference between products from nature and those that are produced synthetically. The same […] risks are present everywhere. (quoted from Sjöström, 2007, p. 88)*

Some political debaters even view the public’s fear of chemicals as an environmental myth, as Hansson (2004) who has claimed that “*there is a ‘chemophobia’ that is close to something paranoid – everything that has to do with chemicals is regarded as bad*” (p. 20; our translation). The quote by Hansson shows that environmental discourses, except from sometimes being impregnated with science rationalistic views, also are political. The discourses show different values and views of what is important and on different risk evaluations. There is a tension between scientific values, which requires evidence, and ethical values, which often claims worst-case scenarios. This was clear in the Swedish debate following Jarl’s documentary “*Underkastelsen*/Submission” (mentioned above), where the former chemistry professor Nils Gösta Vannerberg (2010) was very critical to the movie, whereas Åke Bergman (2010), professor in environmental chemistry and also interviewed in the documentary, supported it. Vannerberg expressed a rationalistic approach, which Sjöström (2007) argues is part of the traditional discourse of chemistry.

Of course, chemical discourses are not only expressed in the (news) media. Other channels of communication can be information from authorities and environmental organizations, but also communication between individuals. Education has a special position when it comes to chemical discourses, because here there is possibility for multiple perspectives (pluralism), reflection and discussion (Sund & Öhman, 2013) – something that is missing in one-way mass communication.

Chemicals education triangle: Risks, actors and discourses

In this chapter we have discussed socio-scientific issues concerning chemicals. We have described and problematized teaching and learning about risk-related chemicals, such as additives, contaminants, pollution and various environmental chemicals. We suggest that *Chemicals Education* should be based on a *Chemicals Education Triangle*, with the following three corners: (1) the nature of chemical risks, (2) the interplay between actors in the chemical society, and (3) pluralism and awareness regarding various chemical discourses. The communication inside and outside the science/chemistry classroom about the interplay between chemistry and society can be analyzed and discussed based on such a triangle. *Chemicals Education* provides tools for the learners to interpret and manage e.g. the complex science-based reporting in especially news media. Therefore, it supports the development of "chemicals *Bildung*" among the learners.

The "chemicals literate" critical-democratic citizen needs: (1) knowledge in and about science; (2) knowledge about media dynamics (media awareness); (3) literacy skills (reading, interpreting and arguing); and (4) discerning habits of mind (e.g. critical and reflective attitude) (Jarman & McClune, 2007, pp. 86-92). This is similar to "critical scientific literacy" (Hodson, 2011) and more generally *Bildung*, as described above. It is about an integrated view on scientific content knowledge, societal context knowledge and values, combined with action competence. From a chemistry content perspective *Chemicals Education* aims at understanding the nature of chemicals (Ngai, Sevian & Talanquer, 2014), natural vs. synthetic substances, doses, solubility, distribution of chemicals etc.

Using multifaceted (Sjöström & Talanquer, 2014) and socio-critical (Marks & Eilks, 2009) approaches to chemistry teaching a critical-reflexive attitude can be reached by the learners (and teachers). With socio-critically-oriented and pluralistic science/chemical education youths get the opportunity to obtain tools necessary to participate in informed decision making concerning, e.g. consumer products and lifestyle, but also democratic choices. In this chapter we have argued that such teaching about SCI, should be permeated with the three corners/perspectives in the "chemicals education triangle": risks, actors and discourses.

We finish the chapter by giving an illustrating example (phthalates) of how the three corners of the chemicals education triangle can be used in science/chemistry education to generate questions:

Corner one – *risks*: What are the properties of various phthalates? What risk assessments have been made? How do they differ and why? What can phthalates be replaced with? Do they decompose? How? To what?

Corner two – *actors*: What applications does various phthalates have? What are the benefits and risks? What is the production volume? Which are the sources of exposure to humans and nature? How has legislation concerning phthalates evolved and why?

Corner three – *discourses*: What do different actors say about the risk? What do media say about the risk? What appears to be the public perception of risk? What (if anything) is said about phthalates in the classroom?

To support the development of critical chemical literacy among the learners we have argued for broad perspectives – both science and society – and pluralism.

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