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Chemistry Teaching for the Future: A model for secondary chemistry education for sustainable development

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For more than 40 years, the international community has acknowledged the role education might play in environmental awareness and conservation. The last major initiative came when the United Nations General Assembly proclaimed a Decade of Education for Sustainable Development (2005–2014). In the final year of the decade, teachers still struggle to realise education for sustainable development (ESD). One of the challenges teachers face with respect to ESD is the inclusion of even more content into an already overloaded curriculum. In response, it has been suggested that ESD should be introduced as an integrated perspective across the content of all existing subjects. This paper offers a model for how ESD can be realised in chemistry education. The model has been developed to support chemistry teachers in their educational planning and consists of 5 categories: chemical content knowledge, chemistry in context, the distinctiveness and methodological character of chemistry, ESD competences and lived ESD. The ESD model is illustrated through 5 ellipses, visualising the hierarchy of the categories, as they exist in different levels. All 5 ESD categories need to be considered in a holistic ESD approach.

Keywords: *Chemistry education; Environmental education; Secondary school*

Introduction

Mass media is a daily reminder of the challenges the world faces, especially in terms of the currently accelerating ecological crisis. From a global perspective, climate change, poverty, pandemics and the lack of pure water and phosphorous are only some of the problems threatening the sustainability of our planet. These problems are expected to accelerate as human pressure on the earth system continues to increase (United

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Nations Environment Programme, 2012). Working towards a development ‘that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (World Commission on Environment and Development, 1987, p. 8) is even more urgent today than when the Brundtland Commission presented this definition of sustainable development in 1987.

Education has been recognised as ‘indispensable’ for achieving sustainable development (United Nations, 2002). Hence, the United Nations proclaimed the decade from 2005 to 2014 to be the international Decade of Education for Sustainable Development. The idea was that governments of all UN member countries commit themselves to focusing on how education could contribute to sustainable development (UNESCO, 2005b).

Chemistry education is considered to have a central role in education for sustainable development (ESD) (Bradley, 2005; Burmeister & Eilks, 2012). This is based on the core roles that chemistry and the chemical industry might play in sustainable development. Because many products in our daily lives are based on chemistry, the chemical industry has a major potential for focusing on the environment in terms of both the production process and the end product. Hence, it has been claimed that chemistry education should emphasise learners’ understanding of the role of chemistry in society and increase their ability to evaluate chemistry-related businesses and products, such as how chemistry can affect the future, contribute to sustainable communities and aid in the proper stewardship of natural resources (Burmeister & Eilks, 2012; Wheeler, 2000).

Chemistry is also important in sustainability issues outside the professional world. Chemical knowledge is necessary for lay people to understand many issues that threaten the sustainability of our planet, such as the mechanisms behind climate change and the potential side effects on our personal lives caused by the production of goods, alternative energy production, etc. (Burmeister, Rauch, & Eilks, 2012; Schmidt & Wolfe, 2009). The pupils of today will become voting citizens who make decisions that involve applications of chemistry. Thus, understanding chemistry concepts will provide informed support for making such decisions (De Vos, Bulte, & Pilot, 2002; Kolstø, 2001; Ware, 2001).

Despite the importance of chemistry in ESD, studies in Germany have revealed that both experienced teachers (Burmeister, Schmidt-Jacob, & Eilks, 2013) and student teachers (Burmeister & Eilks, 2013a) struggled to apply the ideas of ESD and green chemistry in their teaching. These findings concur with a Norwegian study (Sinnes & Jægstad, 2011) that found that science teachers educated for ESD and with an outspoken desire to include ESD in their teaching were not able to do so after their graduation because of the lack of facilitation in the schools. Formal secondary education in Norway has been accused of not prioritising ESD (Brænden, 2008; Koller, 2009; Laumann, 2007; Raabs, 2010; Schreiner, 2006). This phenomenon has been recognised in other countries as well (Palmer, 1998). Other challenges frequently cited as problematic within ESD include time constraints caused by overloaded subjects, lack of teaching resources and issues associated with the subject discipline (Barrett, 2007; Palmer, 1998; Sandell, Öhman, & Östman, 2003).

To overcome these challenges, we present a model for applying ESD from an integrated perspective derived from the already existing subject of chemistry. Thus, we visualise how ESD can be realised in the teaching of chemistry regardless of the focus and subject workload of existing curricula. The model for planning teaching and learning in chemistry presented here attempts to bridge the gap between the school and ‘an ideal and sustainable world’. The model is outlined through a theoretical discussion of how aspects of ESD can be integrated into chemistry education and the following research question is posed: How can secondary school chemistry education be an arena for ESD?

Although this paper provides a within-discipline approach to ESD (Stables & Scott, 2002), the interdisciplinarity that is emphasised in much of the ESD literature (cf. Wals & Jickling, 2002) is also addressed. A key element in ESD is the importance of acknowledging the interrelatedness between the ecological, social and economic dimensions of any issue. While we concede that it is not necessary for one teacher to consider all perspectives of ESD and that collaboration among teachers of different subjects may be beneficial (Borg, Gericke, Höglund, & Bergman, 2012), we still insist that all chemistry teachers should be able to include the ecological, economic and social perspectives of the chemical topics they teach. Thus, we stress that the ability to assess how chemistry affects and is affected by other disciplines is a part of the general education of the chemistry teacher and therefore an integrated element in the model.

Before introducing our model of ESD in chemistry, we will present the perspectives of ESD on which the paper is built. We will also discuss scientific literacy and its relevance to ESD.

Background

Since its introduction, the concept of sustainability has taken on many different meanings and remains highly contested. A study by Dobson (1996) revealed more than 300 different meanings of the terms ‘sustainable development’ and ‘sustainability’. A common division is between those who prioritise ‘sustainable economic growth’ and those who prioritise ‘sustainable human development’. The first group adheres to the current social and economic system and emphasises ‘the role of technological and economical tools in shifting individual, group and industry activities toward a more sustainable path of economic development’ (Fien & Tilbury, 2002, p. 3), whereas the second group focuses on social equity and ecological limits. The latter calls for radical changes in the social and economic system, questioning the present worldview of unlimited economic growth (Fien & Tilbury, 2002; Orr, 1992). There are, however, several nuances to this picture. Due to different understandings about the concept of sustainable development, a myriad of understandings of what ESD is and could be also exists in the ESD literature (Fien & Tilbury, 2002; Gough & Scott, 2006; de Haan, 2010; Huckle, 1996; Orr, 1992).

Combes (2009) claimed that ESD is ‘a learning process and an approach to teaching based on the ideals and principles that underlie sustainability’ (Combes, 2009,

p. 6). Due to the various understandings of sustainability, ESD is, however, not an agreed-upon set of ideas that educators can simply apply to their teaching. Teaching approaches and topics differ according to local contexts and priorities (UNESCO, 2005b, 2012). Sterling (2010) warns against a consensus within the concept of ESD, since a too narrow definition of ESD could cause policies, theories and practices outside the stated boundaries to assume that ESD is not their concern. In addition, it is important to remember what Wals (2011, p. 179) reminded us: ‘what may appear to be sustainable behaviour today may turn out to be unsustainable later in time’. He emphasised the importance of avoiding indoctrination into a set idea of what sustainable development means and rather ‘focus on the kind of capacity building and critical thinking that will allow citizens to understand what is going on in society, to ask critical questions and to determine for themselves what needs to be done’ (Wals, 2011, p. 179).

Summers, Childs, and Corney (2005) referred to a definition of ESD from the British government’s Sustainable Development Education Panel when they stated:

[e]ducation for sustainable development enables people to develop the knowledge, values and skills to participate in decisions about the way we do things individually and collectively, both globally and locally, that will improve the quality of life now and without damaging the planet for the future. (p. 629)

An important aspect of this interpretation is that ESD does not necessarily concern a specific sustainability issue. By all means, ESD may very well deal with a sustainability issue, but the main emphasis is promoting skilled participation in future decisions both locally and globally in a manner that does not negatively affect future generations. A key concept in this respect is the precautionary principle, which emphasises taking action to protect human health and the environment against possible future damage (UNESCO, 2005a).

Burmeister et al. (2012, p. 59) are of similar thinking, emphasising: ‘[t]he central focus of ESD is to prepare the younger generation to become responsible citizens in the future’. The definition of ESD from Summers et al. (2005) and the broad notion of becoming *responsible citizens* provide an important foundation for this paper. The notion of responsible citizens points to respect for other human beings (both present and future generations) and for the planet and what it provides (e.g. resources, flora and fauna), which is a founding value of ESD (UNESCO, 2006). Moreover, the notion of becoming responsible citizens points to Klafki’s (2000) three dimensions of pupils’ capacities: self-determination, participation and expressing solidarity with others. Various levels and dimensions of education must be taken into consideration when educating for sustainable development. There is a need for both taking up socially relevant issues and a general education for societal participation (Burmeister & Eilks, 2013a).

Societal changes continuously increase the demands on and challenges for schools (Kind, 2003). The aims and content of science education are therefore the subjects of a long-debated issue that concerns the relevance of science education (Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013). An important question is whether the way

science is taught in schools provides learners with the knowledge and skills necessary to take part in—and secure—sustainable development. In other words, does science education prepare pupils to make informed decisions in authentic contexts? In their report ‘Science Education in Europe: Critical Reflections’, Osborne and Dillon (2008) pointed to the problem that European science curricula seemed to prepare learners for a science degree instead of meeting the necessities of the majority of pupils who need a broader overview of science. Most pupils need a general science education that prepares them for a critical informed participation in society. Roberts (2011) pointed to the same discrepancy in his distinction between Vision I and Vision II of scientific literacy. Vision I aims to develop ‘a potential pool of scientists’, focusing on the products, processes and the characteristics of science. Vision II focuses on the relevance of science to ‘a variety of science-related situations that confront adults as parents and citizens’ (Roberts, 2011, p. 14). In a knowledge society, there is a need to shift from the scientific literacy of Vision I towards Vision II, which would result in an intermediary position in which both Vision I and Vision II are present (Aikenhead, Orpwood, & Fensham, 2011). The challenge is to develop a science education that prepares pupils for life in a global knowledge society and at the same time provides them with the capability and induce the desire needed to promote sustainable development.

ESD scholars are acknowledged as some of the best-known ‘advocates’ of Vision II of scientific literacy (Roberts, 2011), together with scholars from the science–technology–society movement and the field of socio-scientific issues (Pedersen & Sadler, 2012). Scientific literacy is considered important in order to enable pupils to adapt to the challenges of a rapidly changing world; it is also considered crucial in solving many sustainability issues as a ‘means of enhancing democracy and responsible citizenship, and resisting the consumer juggernaut’ (Hodson, 2008, p. 14). The ability to deal with socio-scientific issues is an integrated component of scientific literacy (Colucci-Gray, Camino, Barbiero, & Gray, 2006). When citizens are able to evaluate and make informed decisions about scientific and socio-scientific matters of personal and public concern, democracy, which is an important element in ESD (Sandell et al., 2003), is strengthened (Hodson, 2008).

In order to make real-life personal decisions and to participate in discussions of scientific issues that affect society, pupils not only need knowledge of scientific content, but also an understanding of how reliable and valid data are collected and interpreted. They need to recognise the tentative character of scientific knowledge and to understand how human interests may shape the process and products of science (Gräber, 2000; Hodson, 2008; Kolstø, 2000). We will therefore build on the literature on both scientific literacy and ESD in our presentation of the ESD in chemistry model. Because sustainable development in itself can be considered a socio-scientific issue (Simonneaux & Simonneaux, 2012), we will also build on the literature from the field of socio-scientific issues.

According to Bybee (1997), the ultimate aim of scientific literacy is *multidimensional scientific literacy*, where students ‘begin to make connections within scientific disciplines, and between science, technology, and the larger issues challenging

society' (Shwartz, Ben-Zvi, & Hofstein, 2006, p. 205). This kind of scientific literacy demands

developing social values such that a person can act in a responsible manner, ... being able to function within the world of work at whatever the skill or responsibility level and possessing the conceptual background or skills of learning to cope with a need-to-have, relevant public understanding of science and technology in a changing society. (Holbrook & Rannikmae, 2007, p. 1353)

These aspects are much in line with the aims of ESD as expressed earlier. We will in particular lean towards the definition of chemical literacy given by Shwartz et al. (2006) that includes four domains they consider necessary to be a chemically literate person (i.e. a graduate of secondary school): general scientific ideas and characteristics of chemistry, chemistry in context, higher order learning skills and affective aspects. These domains will be explained more in depth throughout the paper.

A Chemistry ESD Model

From a broad educational perspective, the chemistry classroom can be an arena for the development of general skills in addition to chemistry-specific skills and knowledge. This is in line with the notion of 'education through chemistry' (Holbrook & Rannikmae, 2007), which includes a shift 'from learning chemistry as a body of knowledge to promoting the educational skills to be acquired through the subject of chemistry' (Holbrook, 2005, p. 4). Thus, the realisation of ESD in the chemistry classroom may not necessarily involve a specific chemical sustainability issue. The teacher may instead, regardless of the chemistry topic being taught, emphasise teaching and learning approaches that promote the development of respect and responsibility among pupils and facilitate the development of the competences pupils need in their daily lives and as adult citizens in a sustainable world.

Burmeister et al. (2012) have presented four strategies for implementing issues of sustainable development in formal chemistry education. They suggest that the following strategies should be implemented in combination for the best possible inclusion of ESD in chemistry education: (1) the adoption of green chemistry principles in *the lab work*, (2) the addition of sustainability strategies as *content* in the chemistry education, (3) the inclusion of *socio-scientific issues* and *controversies* in the teaching and (4) the use of chemistry education as a part of ESD-driven *school development*.

Although Burmeister et al.'s (2012) approach inspired our work, we modified and expanded the strategy, as illustrated in Figure 1. Through this figure consisting of five ellipses, we visualise a model for planning chemistry ESD. The five ellipses represent five different ESD categories, which are chemical content knowledge, chemistry in context, chemistry's distinctiveness and methodological character, ESD competences and lived ESD. The ESD categories represent different aspects of a complex whole and do partly overlap. All of them must be considered in order to achieve a holistic perspective of ESD.

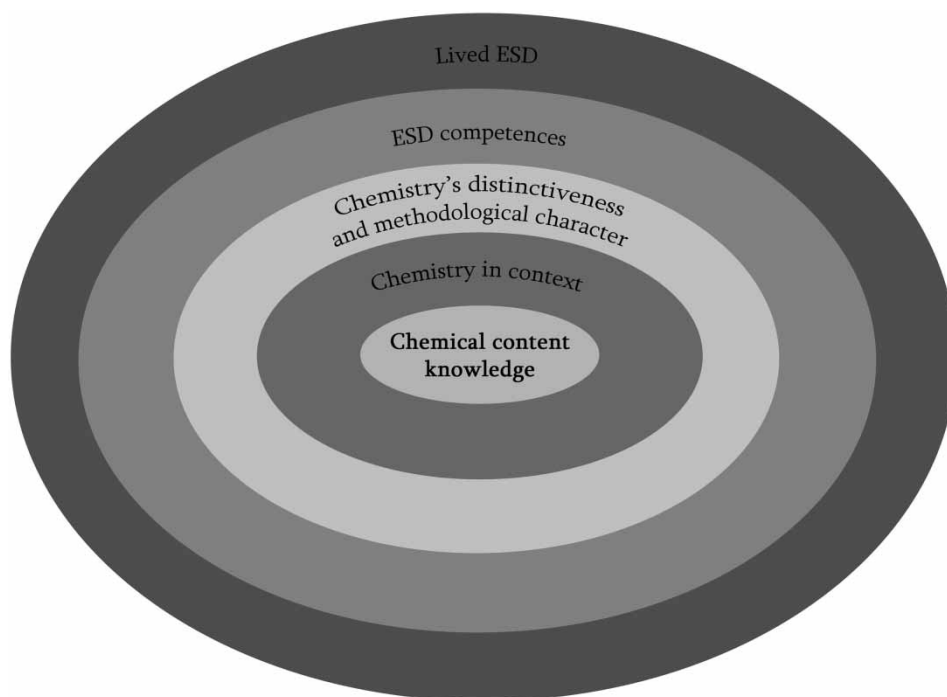


Figure 1. The elliptic model for ESD in chemistry education

The following sections explain the ESD categories and their derivation. We will explain the categories from the centre of the model outward, and therefore start with chemical content knowledge.

Chemical Content Knowledge

The central ellipsis in our model is chemical content knowledge, which is important for understanding and assessing sustainability issues. Content knowledge is important from a curricular argument, since this model is derived from the already existing subject of chemistry. However, content knowledge is also important for pupils to come to grips with socio-scientific issues (Hodson, 2013).

The chemical content knowledge category mainly concerns education *about* sustainable development and emphasises chemistry issues that are relevant for sustainable development. Such issues could be connected to water resources, the effects of acid rain, the ozone layer, oil recovery and searching for renewable sources of energy and raw materials (Burmeister et al., 2012).

A specific example of an issue that is relevant for sustainable development is the life cycle analysis of different products (Juntunen & Aksela, 2013). A life cycle analysis includes analysing the sustainability of the raw materials used in the synthetic strategy, energy use and different types of pollution created by the production process; dangerous compounds in the synthesis process or in the product itself and issues around

waste and waste treatment (Böschén, Lenoir, & Scheringer, 2003). Thus, life cycle analysis is a socio-scientific teaching approach that combines green chemistry, sustainable chemistry and engineering in order to evaluate the environmental burden of a product, process or activity (Juntunen & Aksela, 2013). Topics that can be discussed are among other topics such as water footprint, resource scarcity and the use of different types of materials.

An important aspect of the chemical content knowledge category is the great responsibility given to the teacher with respect to selecting examples and context. Via relevant examples, the pupils will get insight into and knowledge about different sustainability issues. Furthermore, content knowledge in chemistry concerns more than just the issues that are *directly* relevant for sustainable development: background knowledge is also important for understanding the chemistry behind sustainability issues. For example, an understanding of solubility, equilibrium and electrochemical series may be necessary to understand how different substances affect nature.

However, in an ESD-oriented classroom, a sole emphasis on content knowledge is not enough. For example, dealing with the controversial topic of biofuels, where chemical content knowledge is clearly important, the topic should also be considered within a relevant context and with emphasis on specific competences (e.g. systems thinking and normative competence). We will return to the explanation of ESD competences later in this paper, while in the next section, we will proceed with the importance of connecting the content to a relevant context.

Chemistry in Context

Understanding the relations and interdependence of nature, society and the economy is considered crucial to achieving sustainability. Thus, the subject of chemistry must be taught in a relevant context in order to promote full understanding of current sustainability issues. School science engages pupils the most when pupils consider it relevant to their lives and interests (Osborne & Collins, 2001). However, Osborne and Collins (2001) found that physics and chemistry education are less connected to pupils' experiences than are certain topics in biology, such as human biology. Other researchers have also accused chemistry teaching of being irrelevant to pupils' daily lives and have criticised the chemistry curricula for placing the subject first and making its application a poor second (Gilbert, 2006; Holbrook, 2005). This critique has shown that there is significant room for improvement when it comes to making chemistry education context-oriented and relevant for pupils' personal lives.

Stuckey et al. (2013) discussed relevance in science education and defined relevant science education as education that has positive consequences for the pupil—either by fulfilling actual present needs or by fulfilling anticipated future needs. They differentiated between three levels of relevance (individual, societal and vocational) and covered both intrinsic and extrinsic dimensions (Stuckey et al., 2013). From an ESD perspective, the individual dimensions can be exemplified through 'skills for coping with personal life in [the] future' and 'acting responsibly and solidaric in [the] future' (Stuckey et al., 2013, p. 19). The societal dimension is similarly

connected to ESD through examples at an extrinsic level: 'learning how to behave in society' and 'behaving as responsible citizens' (Stuckey et al., 2013, p. 19).

Dillon (2012) pointed to the mutual benefits of realising sustainability issues in both teaching and learning. Pupils become more interested in learning science and they will learn about specific sustainability issues, which in time may contribute to a sustainable future. Thus, the use of specific sustainability issues as a point of departure is a good way to increase the relevance of the subject *and* shed light on a sustainability issue; this can be done on a local level by focusing on sustainability issues in local society. On a global level, the frame of reference could be a specific issue of global sustainability, such as increasing temperatures. Although rising temperatures is a global issue, the consequences vary according to geographical location. As in most global sustainability issues, we do not necessarily experience the consequences, but we are important contributors to their occurrence. This holistic perspective fosters systems thinking as thoughts and beliefs about the future. It also points to a need to care about how we affect other people. Empathy is crucial in order to show respect for both other human beings and the planet; therefore, it is also important for fostering responsible citizens.

Another aspect of the ESD category is connected to the actual teaching of chemistry in other contexts. Experiences in the natural world have an important influence on people's thinking in relation to the environment (Malone, 2008; Palmer, 1998), but the positive experiences need to occur over long periods of time (Hungerford & Volk, 1990). Consequently, including outdoor education in chemistry may have the positive effect of engaging the pupils in sustainability issues and caring for nature (Sandell & Öhman, 2010).

Fieldwork is common in science education, but mostly in biology and geology, where field trips are considered to be an essential part of the subject (Borrows, 2004). Because outdoor education is an important element in ESD (Sandell & Öhman, 2010), it should be integrated in all subjects, including chemistry education. Education in natural environments has rarely been included in the subject of chemistry, and little literature in this field is available. However, some research has focused on linking industries and schools (Coll, Gilbert, Pilot, & Streller, 2013; Hofstein & Kesner, 2006). Using an industry as a site for outdoor education could be beneficial, because learning is made more authentic due to more practical and realistic learning areas (Coll et al., 2013). Thus, scientific questions from everyday life can be discussed, and pupils get experience in objectively evaluating information and get a balanced view of industrial processes (Hofstein & Kesner, 2006). Industrial contexts that include issues related to health and environmental products the pupils use in their daily lives could be beneficial both from a sustainability perspective and when it comes to enhancing pupils' interest and motivation to study chemistry.

Chemistry's Distinctiveness and Methodological Character

The third ellipsis in the model concerns two aspects: applying sustainable practices in chemistry and addressing the nature of chemistry. Central to chemistry education is

the significance of three different levels (Johnstone, 1991). The *macro level* requires describing chemicals and conducting experiments in the laboratory. The chemical reactions at this level can be explained through the different particles and their organisation at the *sub-micro level*. At the *symbolic level*, findings and considerations are reported through formulas, chemical equations and calculations (Herron, 2005; Johnstone, 1991). To understand chemistry, pupils must move across these levels (Ware, 2001). Hence, in chemistry education, practical laboratory work, which is considered essential in developing student knowledge in science (Miller, 2004), is particularly important.

Issues related to sustainable chemistry are often connected to synthesis design and how chemistry and chemicals affect the environment (Böschen et al., 2003). The first aspect of this ellipsis is therefore linked to how to work sustainability into chemistry. Pupils may learn about sustainable industries and *green chemistry* in the laboratory. Green chemistry principles mean working on a small scale to reduce the production of waste, use environmentally friendly chemicals, conserve materials and energy, etc. (Karpudewan, Hj Ismail, & Mohamed, 2011; Ware, 2001). This might be more applicable in tertiary education than in secondary education because tertiary education features greater and more diverse laboratory work. However, awareness can and should be created as early as in secondary school. An early introduction to green chemistry could create different mindsets among pupils, where they consider the environmental effects and are not solely concerned with maximising the experimental yield of the chemical reaction (Ware, 2001). Hence, emphasising green chemistry could contribute to not only an understanding of scientific knowledge and the development of that particular knowledge, but also attitudes and values that are important when realising ESD. In this respect, chemistry education should also centre on philosophical and ethical questions related to the production of chemical knowledge and its applications (Colucci-Gray et al., 2006).

The second aspect of this ellipsis is the nature of chemistry. The nature of chemistry largely includes the nature of science and is therefore connected to the following characteristics of scientific knowledge: it is tentative and never absolute or certain; it is empirically based; it is subjective and therefore influenced by the scientists' beliefs, previous knowledge and experiences; it involves human inference, imagination and creativity and it is socially and culturally embedded (Lederman & Lederman, 2012). According to Kolstø (2000, p. 647), 'the human and social aspects of the product of scientific knowledge have been underemphasized in science teaching'. A chemically literate person understands that chemistry is an experimental subject, whereas chemists make generalisations and suggest theories to explain the world based on scientific inquiry (Shwartz et al., 2006). Learning about scientific research methods is therefore considered an important part of understanding the nature of science (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). This is especially valid for the nature of chemistry due to the importance of laboratory work and the significance of the three different levels that are distinctive to chemistry (Johnstone, 1991, 2000).

Chemistry can, due to the long-time existence of the chemical industry, be considered both a technology and a science (Sjöström, 2007). Hofstein and Kesner (2006, p. 1018) claim that ‘teaching chemistry without incorporating aspects of the chemical industry ignores one of the most important features of modern life and its technological achievements’. They further contend:

We live in an era in which chemistry should be presented to the student not only as a body of knowledge, but also as a vehicle for presenting the technological manifestations of chemistry and its influence on the students’ personal life and the society in which he/she lives. (p. 1037)

The nature of chemistry therefore also includes the role of technology in society.

ESD Competences

The next ellipsis is ESD competences. An important outcome of ESD is developing competences that are considered relevant to contribute to a sustainable future. A competence-based approach to scientific literacy that emphasises ethical competence, communicative competence and other competences encompassing socio-scientific decision-making skills has been highlighted by scholars in the fields of scientific literacy (Gräber, 2000; Holbrook & Rannikmae, 2009) and ESD (de Haan, 2010; OECD, 2005; Salganik, Rychen, Moser, & Konstant, 1999; UNECE, 2011; Wiek, Withycombe, & Redman, 2011). Competences are seen as crucial ‘to tackle the current problems of humankind and the earth’ (Rauch & Steiner, 2013, p. 11), but also to live a life in the knowledge society—where the educational systems have to prepare young people for jobs that do not yet exist (Voogt & Roblin, 2012).

The term *competence* has been interpreted and defined in many ways (Sleurs, 2008; UNECE, 2011; Weinert, 2001). It can be investigated from many perspectives and is therefore considered difficult to define (Kauertz, Neumann, & Haertig, 2012). One definition is ‘the ability to meet demands of [a] high degree of complexity’ (Rychen & Salganik, 2000, p. 67). As a part of the OECD’s project, Definition and Selection of Competences (DeSeCo), Weinert (2001) presented a list of ways in which the term has been defined, described and interpreted theoretically. Despite a thorough analysis, he provided no unified definition of the term. Knain (2005) analysed Weinert’s work and concluded that ‘[o]ne should focus on competences within specific areas rather than general intellectual competences’ (Knain, 2005, p. 128, our translation) and therefore ask which competences one needs to meet specific challenges. A relevant question in this paper is which competences chemistry learners in secondary school will need in order to support both present and future actions for sustainable development.

Even though several lists of competences have been given in both sustainability literature (de Haan, 2010; Wiek et al., 2011) and, in more general, education literature (Voogt & Roblin, 2012), we find that none of them are directly suitable to our model. However, they have informed our task of defining a list of ESD competences. We have, among other frameworks, been inspired by the concept of *Gestaltungskompetenz* (de Haan, 2006, 2010). *Gestaltungskompetenz* or ‘shaping competence’ is linked to

being able to shape our society in a sustainable way, that is, ‘to change economic, ecological and social behaviour without these changes merely being a reaction to existing problems’ (de Haan, 2010, p. 320). *Gestaltungskompetenz* is developed with a foundation in the OECD’s concept of ‘key competencies’ (OECD, 2005) and can be split into 12 sub-competences. Even though the sub-competences are rather specific, they are of a general educational character and we find them too general to simply transfer them to the chemistry classroom.

Another framework that has been important for our development of competences is the twenty-first-century competences. In a study mapping the diversity of competences for the twenty-first century, Voogt and Roblin (2012) analysed eight different frameworks for twenty-first-century competences developed internationally. They found that collaboration, communication and social skills were mentioned in all competency frameworks. In addition, creativity, critical thinking and problem-solving were mentioned in most frameworks (Voogt & Roblin, 2012). Gadotti (2008, p. 24) claimed that ‘[e]ducation for another possible world will be, definitely, an education for sustainability’. Thus, even though the twenty-first-century competences are developed with another purpose than ESD, the competence headings are transferrable to ESD for two reasons. Firstly, both twenty-first-century competences and ESD competences are focused on competences for an unknown future. Secondly, the content of each twenty-first-century heading might be slightly different according to the new context: founded in the chemistry classroom with an emphasis on ESD, the competences might have a different appearance.

Starting out from these frameworks and the question above, we developed a list of nine ESD competences that we consider crucial to support actions for sustainable development. These competences are systems thinking, problem-solving, creativity, critical thinking, action competence, future thinking and belief, normative competence, communication and collaboration. The list of ESD competences emphasises education through science (Holbrook & Rannikmae, 2007) and our view that chemistry ESD should promote general educational skills (Burmeister & Eilks, 2013b) in addition to chemistry-specific skills. Consequently, some of these competences are chemistry-specific with a distinct origin in the chemistry subject, contributing to chemical knowledge and skills. However, some of them are more centred on general competences that are more relevant outside the world of chemistry education. There is a shift in chemistry education worldwide to emphasise the development of higher order cognitive skills, aiming to develop graduates who are ‘capable of evaluative thinking, decision making, problem solving, and taking a responsible action accordingly’ (Zoller, 2004, p. 95). Thus, these kinds of competences should be accounted for in our list—together with the affective aspect of chemical literacy (Shwartz et al., 2006), which is also incorporated in the ESD competences. Each of the nine ESD competences will be described in the following sections.

Systems thinking. Systems thinking can be defined as the ability to ‘analyse complex systems across different domains (society, environment, economy, etc.) and across

different scales (local to global), thereby considering cascading effects, inertia, feedback loops and other systemic features related to sustainability issues and sustainability problem-solving frameworks' (Wiek et al., 2011, p. 207). Systems thinking is therefore considered a key competence to support actions for sustainable development.

In chemistry education, systems thinking is relevant both with respect to understanding scientific working methods and to achieving a holistic understanding of chemistry-related issues. Pupils need to be challenged by systems thinking in order to holistically understand the scientific process of methods, data and conclusions (Kind, 2003). Moreover, systems thinking is crucial in viewing issues from different perspectives. A chemically literate person needs to use his or her chemical understanding as a consumer, in decision-making, in the social debate regarding chemistry-related issues and to understand how innovations in chemistry may affect sociological processes (Shwartz et al., 2006). In chemistry education, a systems thinking perspective may be achieved by investigating environmental, social and economic factors in addition to the chemical content of a specific case. Moreover, the case may be connected to both local and international issues, thereby calling for systems thinking on a global scale as well. Thus, as a part of systems thinking, interdisciplinary and holistic thinking and the understanding of causalities are considered important prerequisites for successfully engaging in sustainability issues (Wheeler, 2000). Due to the complex and pluralistic nature of reality, Rauch and Steiner (2013) urge the need for systems thinking and argue that ESD must not propose a one-sided view; rather, the interdependences between different stakeholders should be recognised and analysed (de Haan, 2010).

Problem-solving. Problem-solving is also frequently emphasised as important in ESD (UNESCO, 2006). We define problem-solving as the ability to solve problems systematically and creatively by assessing the issue or problem, finding and assessing possible solutions and acting upon the solution. Because the chemical industry and research play core roles in finding new solutions for sustainability, chemical problem-solving can be considered especially important. Problem-solving is also important because it practices higher order cognitive skills (Tsaparlis, 2009).

The science classroom has long been acknowledged as an important arena for the development of problem-solving skills in pupils (Garrett, 1987). Good problem-solving skills have also been recognised as a prerequisite for success in chemistry courses. According to Bodner and Herron (2002, p. 235), 'problem-solving is what chemists do, regardless of whether they work in the area of synthesis, spectroscopy, theory, analysis, or the characterisation of compounds'. In chemistry, problem-solving can include theoretical problem-solving exercises that one person may find challenging, but another routine, based on chemical knowledge and experience (Bodner & Herron, 2002). However, the most effective way to develop one's ability to solve problems in chemistry is through practical laboratory work.

Practical laboratory work may have different aims, such as giving the pupils experience in scientific phenomena and related knowledge. Pupils learn *about* science and

how science is created. They learn to *do* science and become interested and motivated in the subject through their experiences in the laboratory (Kind, 2003). Furthermore, connecting laboratory work to scientific working methods and working with real-life examples may help the pupils to understand and connect to sustainability issues (Karpudewan et al., 2011).

Although problem-solving is listed as a specific competence in our work, it is a broad term. Closer examination of the definition and the different levels of chemistry reveals that the term implies other competences as well. Being a good problem solver requires creativity in order to develop possible solutions, and results need to be assessed through both systems thinking and critical thinking.

Creativity. Creative thinking refers to ‘*how* people approach problems and solutions—their capacity to put existing ideas together in new combinations’ (Amabile, 1998, p. 79). A future of climate change and major sustainability challenges demands creative citizens who are able to think innovatively and create new solutions. Creativity is therefore regarded as a crucial competency within sustainability education (Daskolia, Dimos, & Kamylyis, 2012). Creativity is a crucial part of both chemistry education and scientific working methods. The design of new research questions and models requires creativity (Kind, 2003; Osborne et al., 2003). According to Hodson (1992, p. 546), a chemist requires a special kind of knowledge and understanding that ‘combines conceptual understanding with elements of creativity, experimental flair, the scientific equivalent of the gardener’s “green fingers” and a complex of affective attributes that provide the necessary impetus of determination and commitment’.

Amabile (1998) claimed that creativity presupposes an interrelationship between three different factors: in order to be creative, a person must first have technical, procedural and intellectual knowledge about the topic (i.e. expertise). Secondly, the person needs to know different ways to approach the problem creatively (i.e. creative thinking skills). Finally, he or she needs motivation—and intrinsic motivation (i.e. a person’s internal desire to do something) is more valuable than extrinsic motivation (Amabile, 1998). Thus, creativity is connected to other categories in the model, such as chemical content knowledge and chemistry’s distinctiveness and methodological character.

Critical thinking. Critical thinking is a desired goal in science education in general and in assessing sustainability issues in particular. Thus, a clear synergy exists between science education and ESD (Balcaen, 2007). Being able to think critically about issues enables people to examine economic, environmental and social structures while exploring solutions for sustainable development (Tilbury & Wortman, 2004). Critical thinking entails the ability to assess information from both government and lay people. Working with sustainability issues, a lot of the information is of ‘the science-in-the-making kind’ and may even be ‘located at or near the cutting edge of

research' (Hodson, 2013, p. 317). Pupils therefore need to assess and detect reliability in information from a variety of sources.

The essence of critical thinking is the quality of thought, not whether the answer is correct (Bailin, 1998; Balcaen, 2007). In ESD, critical thinking can therefore be linked to the ability to consider different perspectives and forms of knowledge in order to describe (non-)sustainable phenomena, to consider information from different perspectives, to evaluate (non-)sustainable actions and patterns of behaviour and to analyse the risk and hazards (de Haan, 2010). Moreover, critical thinking in ESD allows for reconceptualising what ESD needs to be in changing times and contexts (Wals, 2011).

An important aim of scientific literacy is that pupils develop an educational basis for understanding and managing socio-scientific issues (De Vos et al., 2002; Kolstø, 2001). Kind (2003) emphasised the importance of creating a foundation for working with socio-scientific issues through open-ended experiments. During practical experiments, pupils must critically assess research methods and results (Kind, 2003; Kolstø, 2000). Hence, qualities of critical thinking, such as analysis and argumentation, can be developed through practical work. Furthermore, from a scientific literacy perspective, Tal and Kedmi (2006) suggested using everyday relevant issues to engage students in decision-making processes, because pupils need to

actively interact with social partners, share and communicate in identifying problems, asking questions, constructing and analyzing arguments, judging credibility of sources, interpreting data, hypothesizing, concluding, making value judgments and so forth—all which [are] identified as critical thinking or higher order thinking. (p. 617)

Shwartz et al. (2006) also emphasise the importance of higher order learning skills within their definition of a chemically literate person. The ability to raise questions, look for and relate to information and analyse the loss or benefit in any debate are the skills they bring forward.

Several scholars also point to the aspect of action as an integrated part of critical thinking (Bailin & Siegel, 2003). According to Siegel, a critical thinker is one who is 'appropriately moved by reasons' (Siegel, 1988, p. 23). He emphasised two components of critical thinking: reason assessment and a critical spirit. Hence, critical thinkers must have higher order learning skills to be able to reason well in order to construct and evaluate solutions. They should be able to follow patterns of reasoning, but they should also be motivated by the critical spirit to act upon them (Cuypers, 2004; Siegel, 1988). Due to this element of action, critical thinking partly overlaps with the next competence: action competence.

Action competence. Rudsberg and Öhman (2010) suggested that one aim of ESD could be to enhance pupils' competence in democratic action. Although *action competence* can be viewed as the final aim of ESD, it is also listed as a distinct competence in our framework. In the question regarding the foundation of the ESD competences, we pointed to competences that support *actions* for sustainable development. This

concur with Mogensen and Schnack (2010), who claimed that action competence is an education ideal that is in line with ESD. Action competence includes ‘the capacity to be able to act, now and in the future, and to be responsible for one’s actions’ (Jensen & Schnack, 1997, p. 175).

According to Kolstø (2000, p. 660), ‘science education for action may not necessarily include the action itself. What is important is that the students are trained in articulating and in arguing their views, and in interpreting scientific information in adequate ways’. Jensen (2004) agreed that action competence is developed when pupils are allowed to work with authentic problems, and he presented four dimensions according to which any environmental topic can be viewed and analysed. These dimensions, which also can be used in analysing chemistry-related issues, are as follows:

- Knowledge about effects: What kind of problem is it?
- Knowledge about root causes: Why do we have the problems we have?
- Knowledge about change strategies: How do we change things?
- Knowledge about alternatives and visions: Where do we want to go?

Environmental education is often restricted to the first question, that is, knowledge about the effect. However, including the analysis and understanding of possible visions and changes not only increases the development of action competence, but also contributes to the development of the other ESD competences presented in our model, such as problem-solving, creativity and critical thinking. Moreover, as Jensen (2004, p. 416) pointed out, ‘this is particularly important at a time when increasing globalization and individualization is leading to action-paralysis’, an observation that leads to the next competence: future thinking and belief.

Future thinking and belief. Jensen and Schnack (1997) emphasised the importance of not instilling anxiety and worry in pupils when discussing environmental problems in the classroom. They called for an emphasis on future thinking and belief. Traditionally, a science-oriented approach to environmental education would emphasise theoretical knowledge about environmental issues and descriptions of increasingly worsening conditions; this could lead to a feeling of disempowerment among the pupils. Instead of inducing this ‘learned hopelessness’ and apathy among the pupils (Nagel, 2005), teaching needs to induce courage, commitment and the desire to solve problems. ESD should not be limited to a pessimistic discussion of global problems. These problems should not be denied, but rather presented as ‘fundamentally manageable [in order to] generate and strengthen young people’s optimism about the future’ (Rauch & Steiner, 2013, p. 14). Thus, an education focused on finding solutions and acting upon these solutions is important. Future thinking and belief is hence very closely linked to action competence.

Future thinking is also an important aspect of the distinctiveness of the chemistry subject. If we think about chemical research and the nature of the chemistry subject, future thinking is very relevant, since research in general demands future

thinking. Innovations in chemistry may contribute to finding solutions to different kinds of problems with respect to the environment, health issues and other societal problems. As part of the *Gestaltungskompetenze*, de Haan (2010) emphasised the importance of thinking and acting in a forward-looking manner, both professionally within a future scientific context and personally in the pupils' own lives. The pupils should be able to

assess and apply the findings of future research in the drafting of sustainable development processes; ... recognise their own potential future needs; ... describe the need for providing a greater social security in the future based on their own situation [and] ... identify, analyse and assess examples of focusing on the present, starting from their own lives. (de Haan, 2010, p. 322)

In addition, he emphasised the importance of (1) understanding that current actions should be beneficial for future development and future generations and (2) coping with personal dilemmas in decision-making (de Haan, 2010).

Normative competence. Normative competence is yet another crucial competence that pupils develop through ESD (Wiek et al., 2011). Östman and Almqvist (2011) claimed that normative aspects (i.e. norms, values, interests, worldviews and power) must be dealt with in science education in order to foster competent citizenship. As expressed earlier, respect for other human beings is a foundational value in ESD, through which pupils also need to develop solidarity with others and concern for the future of humans and nature (de Haan, 2010). An important aspect of this development is the ability to see multiple sides of an issue and to consider the opinions of other people. Decisions should be both knowledge-based and value-based, which means that during decision-making, the views of all people should be considered, including the antagonists (Kolstø, 2000).

Keywords describing this competence are therefore empathy, solidarity, attitudes and values, all of which should be addressed in school (Eilam & Trop, 2010). Knowing how to respond actively to environmental questions requires being conscious of one's own values and the ability to understand the choices and consequences for those involved (van Marion, 2008). Hence, chemistry education could be an arena for raising such questions, thus stimulating the normative competence of pupils.

Krageskov Eriksen (2002) added to the idea of normative competence through her elaboration on an ethical sphere of chemistry education. She distinguished between ontological knowledge (i.e. knowledge about chemical compounds, concepts and laws), the epistemological sphere (i.e. understanding chemistry as both an activity and a scientific community) and the ethical sphere. The latter 'contains knowledge of chemistry in a social context, including the question of how chemistry is part of society and which (ethical) considerations should be made in this regard' (Krageskov Eriksen, 2002, p. 7). Ethics in chemistry education often involve 'good science', which includes an awareness of issues such as misconduct, fraud, patents, the use of animal and human research subjects, etc. However, ethics in chemistry education should also

be connected to societal awareness in both local and global contexts. As Krageskov Eriksen claimed (pp. 9–10),

ethical reflection in the context of chemical education comes to mean the reflections on the role of chemistry in society and hence on the values underlying this interplay—and, bearing the ideal of reflectivity in mind, the action for adjustment of the values to the social challenges of today and tomorrow.

Finally, an important part of normative competence is the ability to enjoy the benefits and experience of nature. Sandell and Öhman (2010) pointed to a problematic tendency of ESD: sustainability issues often become anthropocentric and nature is neglected when different interests are considered. Sandell and Öhman therefore stress the value of outdoor education and its ability to widen the scope of ESD as well as awareness of the role of nature.

Communication and collaboration. Finally, communication and collaboration are two interpersonal competences. Pupils need to be able to communicate (verbally, visually and in writing) with other people and clearly express their ideas. Pupils also need to listen to and respect the opinions and feelings of others. Thus, communication is closely connected to the normative competence. Moreover, in chemistry education, the communication of results, controversies, etc. is an important part of the subject.

In addition, pupils have to be able to collaborate with other people, regardless of personalities and backgrounds, in both professional and personal life. Collaboration between people across and within subject areas is important in the research and development of chemical knowledge. Collaboration is also crucial in solving more specific sustainability issues. The increasing complexity of society demands interdisciplinary collaborators rather than lone geniuses (Wagner, 2012). The pupils therefore need to understand and appreciate the fact that collaboration can lead to better end results than individual work, even though the process may be harder. The outcome of collaboration is not only directed towards the product, but also the process where other competences, such as creativity, problem-solving, critical thinking, systems thinking and communication, can also be developed. However, effective collaboration must be learned and requires guidance and experience (Blatchford, Kutnick, Baines, & Galton, 2003).

Summary of the ESD competences. In our model, nine competences are considered crucial to support actions for sustainable development: systems thinking, problem-solving, creativity, critical thinking, action competence, future thinking and belief, normative competence, communication and collaboration.

The list of ESD competences is not finite. Developing competences is viewed as an ongoing, lifelong process of learning (Rychen & Salganik, 2000). The importance of different competences varies across regions of the world according to cultural norms, technological access and social and power relations (OECD, 2005). Views of 'relevant' learning outcomes also depend on context (de Haan, 2010; Knain, 2005).

However, a main aspect of the concept of competences is the ability to transfer competences from one situation and use them in another setting (Kauertz et al., 2012). Our list of competences has, therefore, a foundation in chemistry education, but is thought to cover situations pupils also need outside the chemistry classroom. The aim has been to identify competencies that are broad enough to cover different aspects and nuances of ESD, but at the same time precise enough for teachers to focus on, one or more at a time, when chemistry lessons are planned and evaluated. Similar to Holbrook's (2005) concept of education through chemistry, the chemistry classroom can be an arena for pupils to develop ESD competences while they acquire knowledge about chemistry; this can lead pupils towards self-regulated learning (Gräber, 2000).

Lived ESD

The last ellipsis in our model outlines how ESD principles are realised in classroom and school cultures, providing pupils with an opportunity to experience sustainable living. Lived ESD is situated in the outer ellipsis of the model indicating that this category influences all educational experiences, both within the chemistry classroom in particular and in the school culture in general.

Teachers can be influenced to focus more on ESD if an ESD school culture is established at the school. An ESD school culture is characterised by a respect for the environment and democratic principles. Sterling (2009) describes sustainable schools as schools where collaboration, flexibility and trust are important; where diversity is valued and where everyone is treated with respect. In a sustainable school culture, the principles of sustainability also extend to school management. Examples could include energy-saving measures as well as facilities for sorting waste, ecological food and school gardens. The effectiveness of these small energy contributions on the global environment may be questionable, but as Jensen and Schnack (1997) pointed out, the crucial factor is what the pupils actually learn from participating in such activities. By engaging in such activities and experiencing how sustainability is realised at the school level, pupils should begin to learn how to live sustainable lives (Sterling, 2009).

Although our framework is directed towards the chemistry classroom and not school management, such measures of sustainability by the school could influence the chemistry classroom and the perception of the role of the teacher in the classroom. Indeed, classroom culture reflects the culture of the school and its values. However, classroom cultures can also affect the school culture if the particular classroom culture is spread to other classrooms (Bronfenbrenner, 1994).

The teacher plays a major role in establishing a classroom culture that corresponds with the principles of ESD. Borg et al. (2012) investigated teachers' subject-bound differences in realising ESD. They found that teachers were strongly influenced by their own education and that they were likely to build their understanding of sustainable development on the foundation of the traditions they had experienced through their studies. Science teachers hence tended to be oriented towards the fact-based

teaching tradition, instead of a pluralistic teaching tradition, which acknowledges different perspectives, views and values (Borg et al., 2012). This might raise a specific challenge for science teachers with respect to realising ESD and their choice of teaching strategies. Teaching should move away from what Jickling and Wals (2013, p. 78) call ‘big brother sustainable development’, in which the view of education is instrumental and deterministic, and towards a socio-constructivist and transformative view about education which in turn would be more emancipatory. In order to achieve such a change in pedagogy, teacher education in ESD is essential mainly because a reform in teaching practice must begin in the teacher education programme (Burmeister & Eilks, 2013b).

The role of the teacher is not only choosing an appropriate pedagogy. The teacher is important as a role model as well and can, according to Hungerford and Volk (1990), have a significant influence on pupils’ thinking in relation to the environment. The teacher also has a significant role in creating a friendly, empowering and safe learning environment. Within this learning environment, the same emphasis on collaboration, flexibility, trust, respect and diversity should be acknowledged (Sterling, 2009).

The elements of lived ESD discussed in this section are relevant also to the lives of the pupils outside school. As a part of lived ESD, we can cross school borders to connect social sustainability and democracy to the surrounding society. Through the linking of chemistry content to specific local contexts and locally relevant sustainability issues, pupils may be assisted in understanding their local community and its related issues—further serving to encourage community engagement. We can also make a linkage between the chemistry classroom and the chemical industry (Hofstein & Kesner, 2006), as discussed earlier in this paper.

Elaborating and Clarifying the Elliptic ESD Model as a Model for Teaching and Learning

In this paper, we discussed how chemistry education could become an arena for ESD. We have already introduced the elliptic model of ESD in chemistry education (Figure 1). The model consists of five ESD categories, all represented by an ellipsis. The three central ellipses of the model are strongly connected to the subject of chemistry, whereas the remaining two ellipses have a more general educational character. Figure 2 shows a comprehensive version of the same model, including subcategories of each ESD category. The five ellipses in the model visualise the different levels of the five ESD categories and exemplify how the ideas that underlie the elliptic model could be realised in chemistry education. Even though ESD has a diverse and multidimensional nature and the ESD categories are intertwined, they can be realised in chemistry education and thought about as different ‘layers’. This emphasis on the different layers will allow teachers to introduce ESD gradually and to scatter it throughout their teaching. The model is also relevant and adaptable within different contexts. A change of context may alter the content of the ESD categories and the priority of the subcategories, but the model will still be applicable.

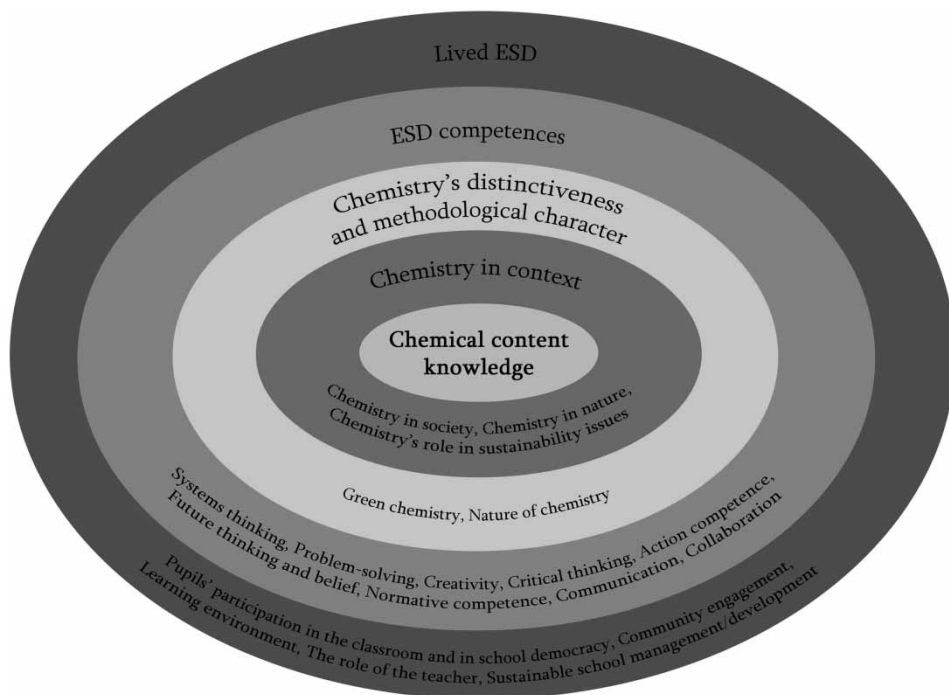


Figure 2. The elliptic model of ESD in chemistry education: a model for planning and analysing chemistry ESD

At the centre of the elliptic model of ESD is chemical content knowledge. The content knowledge is centred in the middle because this is where a secondary school teacher usually would start his or her educational planning, deciding what the chemical topic of the lesson should be. The choice of topic would generally be based on curricula, annual plans and other leading documents. Chemical content knowledge can comprise either direct knowledge about sustainable development issues or background knowledge that can be situated in various contexts, thus linking the content knowledge to sustainable development. On the other hand, many issues and topics taught in the chemistry classroom will not be connected to sustainable development. Nevertheless, through the elliptic model, we want to show that regardless of sustainability focus, the chemistry classroom may be an arena for ESD simply by focusing on the other ellipses in the model, hence the previously mentioned aim of bridging the gap between the school and ‘an ideal and sustainable world’.

Continuing outward in the model, we find chemistry in context. Situating the subject within a context is especially important in ESD and can be done regardless of the sustainability focus. After the content of the lesson is chosen, selection of context would be a reasonable next step. Typical questions for the teacher to ask are: Can the content be made relevant for the pupils by connection to a context that is familiar? Can the content be linked to a sustainability issue? Should this topic be taught in an outdoor environment? The subject in connection to nature

and/or society will not only increase the relevance of the subject for pupils, but also lead them to practice systems thinking and other competences. This is just one example of the overlapping and holistic nature of the model. If the context is related to a sustainability issue, light will also be shed on the specific sustainability issue and pupils may develop both knowledge and personal concern about the issue.

Chemistry's distinctiveness and methodological character emphasises green chemistry and the nature of chemistry. This can be enhanced through practical work connecting the three levels of chemistry—the microscopic, sub-micro and symbolic levels (Johnstone, 1991)—and through real-life issues. By consciously reflecting on green chemistry principles and the nature of chemistry, pupils may increase their understanding of the scientific process in chemistry in particular and in science in general.

The next ellipsis is ESD competences. ESD competences may be the foundation of all working methods of teaching and learning. Regardless of topic and context, the teacher could emphasise the development of specific ESD competences in all pupils. Thus, having a conscious focus on selecting teaching and learning methods would contribute to the development of these competences. Pupils will have different needs depending on age and individual differences, and development of one competence must therefore occur gradually and in a planned manner. Hence, a strategy with respect to the development of the ESD competences is suggested.

Finally, in the outer ellipsis of the model, we find lived ESD. Lived ESD could be considered a frame within which the other ESD categories lie, as illustrated by the position in the elliptic model. The category includes ESD keywords such as social sustainability and democracy; social sustainability offers the pupils a friendly and safe learning environment both in the classroom and at each school level and democracy is connected to pupil participation. Thus, the category involves both the role of the teacher in creating a friendly and safe learning environment (characterised by ESD principles) and the importance of a sustainable school culture. Lived ESD is emphasised as a part of the general education in schools, but is also transferable to the lives the students live outside school.

A challenge often experienced within ESD is maintaining a balance between subject-specific and general ESD perspectives. A limitation of ESD models, as in much interdisciplinary work, may be that the model is either too oriented to chemistry (i.e. too specific) or is too general. A model that is too general may suffer from the lack of approval by teachers because it might subsume the subject of chemistry. Furthermore, the application of the model could compete with the objectives of the curriculum. On the other hand, a model that is too chemistry-oriented risks being limited by the fact-based teaching tradition, thus failing to meet the goals of general education necessary in ESD. Hence, the chemistry education could fail to contribute to the preparation of responsible citizens, which is an aim of ESD. In our model, the balance between three subject-specific ellipses and two ellipses that are oriented towards general education attempts to prevent such limitations. Thus, teachers can see the two outer ellipses as the foundation of all chemistry-oriented teaching and learning activities to educate for sustainable development through the subject of chemistry.

For many teachers, emphasising ESD competences and lived ESD would be a good way to begin realising ESD in their teaching. This especially accounts for curricula that are not explicitly oriented towards ESD. The model can still be applied in these settings through a conscious focus on green chemistry, the nature of chemistry, connecting the subject to a relevant context, emphasising different competences in an education through science perspectives and fostering a classroom atmosphere characterised by lived ESD. Furthermore, to achieve the holistic ESD perspective, examples relevant for sustainable development should be included when appropriate. Most chemistry topics (e.g. equilibrium, acids and bases, electrochemical reactions, etc.) need to be taught within a context, and the teacher therefore has great influence when it comes to selection of examples and thereby context.

Conclusion

The ESD model presented in this paper provides a perspective from which to develop a sustainable chemistry education within the current chemistry curriculum. Overloaded subjects are one of the challenges teachers point to when attempting to realise ESD in their classrooms. This model therefore presents a way to realise ESD in chemistry education without adding more content knowledge to the curriculum. The elliptic model of ESD in chemistry education is developed in order to support teachers in their realisation of ESD and could therefore be presented during in-service and pre-service teacher education programmes. Introducing a model such as the elliptic ESD model is, however, not enough to enable the teachers to educate for a sustainable development. They also need adequate education in order to realise the specific subcategories. Moreover, the teachers must prioritise the different categories and subcategories of this model; further, we have emphasised the significant selection of content, context, examples and pedagogy. Facilitation for teachers to realise ESD is also the teachers' desire to actually realise ESD in their future classrooms (Scott, 1996). All these perspectives must therefore be addressed in teacher education aiming at ESD.

Disclosure statement

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References

- Aikenhead, G., Orpwood, G., & Fensham, P. (2011). Scientific literacy for a knowledge society. In C. Linder, L. Östman, D. A. Roberts, P.-O. Wickman, G. Erickson, & A. MacKinnon (Eds.), *Exploring the landscape of scientific literacy* (pp. 28–44). New York, NY: Routledge.
- Amabile, T. M. (1998). How to kill creativity. *Harvard Business Review*, 76(5), 77–87.
- Bailin, S. (1998). Education, knowledge and critical thinking. In D. Carr (Ed.), *Education, knowledge and truth: Beyond the postmodern impasse* (pp. 204–220). London: Routledge.
- Bailin, S., & Siegel, H. (2003). Critical thinking. In N. Blake, P. Smeyers, R. Smith, & P. Standish (Eds.), *The Blackwell guide to the philosophy of education* (pp. 181–193). Oxford: Blackwell.

- Balcaen, P. L. (2007). Tweaking conventional science curriculum: Addressing synergies between environmental science and a model for teaching critical thinking. In D. B. Zandvliet & D. Fisher (Eds.), *Sustainable communities, sustainable environments: The contribution of science and technology education* (pp. 13–22). Rotterdam: Sense.
- Barrett, M. J. (2007). Homework and fieldwork: Investigations into the rhetoric–reality gap in environmental education research and pedagogy. *Environmental Education Research*, 13(2), 209–223.
- Blatchford, P., Kutnick, P., Baines, E., & Galton, M. (2003). Toward a social pedagogy of classroom group work. *International Journal of Educational Research*, 39(1), 153–172.
- Bodner, G. M., & Herron, J. D. (2002). Problem-solving in chemistry. In J. K. Gilbert, O. D. Jong, R. Justi, D. F. Treagust, & J. H. V. Driel (Eds.), *Chemical education: Towards research-based practice* (pp. 235–266). Dordrecht: Kluwer Academic.
- Borg, C., Gericke, N., Höglund, H.-O., & Bergman, E. (2012). The barriers encountered by teachers implementing education for sustainable development: Discipline bound differences and teaching traditions. *Research in Science & Technological Education*, 30(2), 185–207.
- Borrows, P. (2004). Chemistry trails. In M. Braund & M. J. Reiss (Eds.), *Learning science outside the classroom* (pp. 151–168). London: RoutledgeFalmer.
- Böschen, S., Lenoir, D., & Scheringer, M. (2003). Sustainable chemistry: Starting points and prospects. *Naturwissenschaften*, 90(3), 93–102.
- Bradley, J. D. (2005). Chemistry education for development. *Chemical Education International*, 6(1), 1–6.
- Brænden, M. (2008). *Undervisning for bærekraftig utvikling: finnes det en sammenheng mellom teori og praksis? En studie av hvordan naturfagslærere på ungdomstrinnet følger opp FN's Utdanningsår for Bærekraftig Utvikling* [Science education for sustainable development. A study of how lower secondary school science teachers follow up the UN decade of ESD] (Master's thesis). Norwegian University of Life Sciences, Ås.
- Bronfenbrenner, U. (1994). Ecological models of human development. In M. Gauvain & M. Cole (Eds.), *Readings on the development of children* (2nd ed., pp. 37–43). New York: Freeman.
- Burmeister, M., & Eilks, I. (2012). An example of learning about plastics and their evaluation as a contribution to education for sustainable development in secondary school chemistry teaching. *Chemistry Education Research and Practice*, 13, 93–102.
- Burmeister, M., & Eilks, I. (2013a). An understanding of sustainability and education for sustainable development among German student teachers and trainee teachers of chemistry. *Science Education International*, 24(2), 167–194.
- Burmeister, M., & Eilks, I. (2013b). Using participatory action research to develop a course module on education for sustainable development in pre-service chemistry teacher education. *Centre for Educational Policy Studies Journal*, 3(1), 59–78.
- Burmeister, M., Rauch, F., & Eilks, I. (2012). Education for Sustainable Development (ESD) and chemistry education. *Chemistry Education Research and Practice*, 13, 59–68.
- Burmeister, M., Schmidt-Jacob, S., & Eilks, I. (2013). German chemistry teachers' understanding of sustainability and education for sustainable development—an interview case study. *Chemistry Education Research and Practice*, 14, 169–176.
- Bybee, R. W. (1997). Towards an understanding of scientific literacy. Scientific literacy: Science education and secondary school student. In W. Gräber & C. Bolte (Eds.), *Scientific literacy* (pp. 37–68). Kiel: Institut Für die Pädagogik Naturwissenschaften an der Universität Kiel.
- Coll, R. K., Gilbert, J. K., Pilot, A., & Streller, S. (2013). How to benefit from the informal and interdisciplinary dimension of chemistry in teaching. In I. Eilks & A. Hofstein (Eds.), *Teaching chemistry—a studybook. A practical guide and textbook for student teachers, teacher trainees and teachers* (pp. 241–268). Rotterdam: Sense.
- Colucci-Gray, L., Camino, E., Barbiero, G., & Gray, D. (2006). From scientific literacy to sustainability literacy: An ecological framework for education. *Science Education*, 90(2), 227–252.

- Combes, B. P. Y. (2009). The United Nations Decade of Education for Sustainable Development (2005–2014): Learning to live together sustainably with the Earth. *Revista de la Cátedra Unesco sobre Desarrollo Sostenible de la UPV/EHU*, 3, 5–13.
- Cuyppers, S. E. (2004). Critical thinking, autonomy and practical reason. *Journal of Philosophy of Education*, 38(1), 75–90.
- Daskolia, M., Dimos, A., & Kampylis, P. (2012). Secondary teachers' conceptions of creative thinking within the context of environmental education. *International Journal of Environmental and Science Education*, 7(2), 269–290.
- De Vos, W., Bulte, A., & Pilot, A. (2002). Chemistry curricula for general education: Analysis and elements of a design. In J. K. Gilbert, O. D. Jong, R. Justi, D. F. Treagust, & J. H. V. Driel (Eds.), *Chemical education: Towards research-based practice* (pp. 101–124). Dordrecht: Kluwer Academic.
- Dillon, J. (2012). Science, the environment and education beyond the classroom. In B. J. Fraser, K. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education* (pp. 1081–1095). New York, NY: Springer.
- Dobson, A. (1996). Environment sustainabilities: An analysis and a typology. *Environmental Politics*, 5, 401–428.
- Eilam, E., & Trop, T. (2010). ESD pedagogy: A guide for the perplexed. *The Journal of Environmental Education*, 42(1), 43–64.
- Fien, J., & Tilbury, D. (2002). The global challenge of sustainability. In D. Tilbury, R. B. Stevenson, J. Fien, & D. Schreuder (Eds.), *Education and sustainability: Responding to the global challenge* (pp. 1–12). Gland: Commission on Education and Communication, IUCN.
- Gadotti, M. (2008). What we need to learn to save the planet. *Journal of Education for Sustainable Development*, 2(1), 21–30.
- Garrett, R. (1987). Issues in science education: Problem-solving, creativity and originality. *International Journal of Science Education*, 9(2), 125–137.
- Gilbert, J. K. (2006). On the nature of “context” in chemical education. *International Journal of Science Education*, 28(9), 957–976.
- Gough, S., & Scott, W. (2006). Education and sustainable development: A political analysis. *Educational Review*, 58(3), 273–290.
- Gräber, W. (2000). Aiming for scientific literacy through self-regulated learning. In G. Stochel & I. Maciejowska (Eds.), *Interdisciplinary education—challenge of 21st century* (pp. 101–108). Krakow: Tempus Seminar. Retrieved from <http://www.chemia.uj.edu.pl/~nest/Proceedings.pdf#page=101>
- de Haan, G. (2006). The BLK ‘21’ programme in Germany: A ‘Gestaltungskompetenz’-based model for education for sustainable development. *Environmental Education Research*, 12(1), 19–32. doi:10.1080/13504620500526362
- de Haan, G. (2010). The development of ESD-related competencies in supportive institutional frameworks. *International Review of Education*, 56(2–3), 315–328. doi:10.1007/s11159-010-9157-9
- Herron, J. D. (2005). Introduction to chemists' guide to effective teaching. In N. J. Pienta, M. M. Cooper, & T. J. Greenbowe (Eds.), *Chemists' guide to effective teaching* (Vol. 1, pp. 2–11). Upper Saddle River, NJ: Pearson Education.
- Hodson, D. (1992). In search of a meaningful relationship: An exploration of some issues relating to integration in science and science education. *International Journal of Science Education*, 14(5), 541–562.
- Hodson, D. (2008). *Towards scientific literacy—a teachers' guide to the history, philosophy and sociology of science*. Rotterdam: Sense.
- Hodson, D. (2013). Don't be nervous, don't be flustered, don't be scared. Be prepared. *Canadian Journal of Science, Mathematics and Technology Education*, 13(4), 313–331. doi:10.1080/14926156.2013.845327

- Hofstein, A., & Kesner, M. (2006). Industrial chemistry and school chemistry: Making chemistry studies more relevant. *International Journal of Science Education*, 28(9), 1017–1039. doi:10.1080/09500690600702504
- Holbrook, J. (2005). Making chemistry teaching relevant. *Chemical Education International*, 6(1), 1–12.
- Holbrook, J., & Rannikmäe, M. (2007). The nature of science education for enhancing scientific literacy. *International Journal of Science Education*, 29(11), 1347–1362. doi:10.1080/09500690601007549
- Holbrook, J., & Rannikmäe, M. (2009). The meaning of scientific literacy. *International Journal of Environmental & Science Education*, 4(3), 275–288.
- Huckle, J. (1996). Realizing sustainability in changing times. In J. Huckle & S. Sterling (Eds.), *Education for sustainability* (pp. 3–17). London: Earthscan.
- Hungerford, H. R., & Volk, T. L. (1990). Changing learner behavior through environmental education. *The Journal of Environmental Education*, 21(3), 8–21. doi:10.1080/00958964.1990.10753743
- Jensen, B. B. (2004). Environmental and health education viewed from an action-oriented perspective: A case from Denmark. *Journal of Curriculum Studies*, 36(4), 405–425. doi:10.1080/0022027032000167235
- Jensen, B. B., & Schnack, K. (1997). The action competence approach in environmental education. *Environmental Education Research*, 3(2), 163–178. doi:10.1080/1350462970030205
- Jickling, B., & Wals, A. E. (2013). Probing normative research in environmental education. In R. B. Stevenson, M. Broady, J. Dillon, & A. E. Wals (Eds.), *International handbook of research on environmental education* (pp. 74–86). New York: Routledge.
- Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*, 7, 75–83. doi:10.1111/j.1365-2729.1991.tb00230.x
- Johnstone, A. H. (2000). Teaching of chemistry—logical or psychological? *Chemistry Education Research and Practice*, 1(1), 9–15. doi:10.1039/a9rp90001b
- Juntunen, M., & Aksela, M. (2013). Life-cycle thinking in inquiry-based sustainability education—effects on students' attitudes towards chemistry and environmental literacy. *CEPS Journal*, 3(2), 157–180.
- Karpudewan, M., Hj Ismail, Z., & Mohamed, N. (2011). Greening a chemistry teaching methods course at the school of educational studies, Universiti Sains Malaysia. *Journal of Education for Sustainable Development*, 5(2), 197–214. doi:10.1177/097340821100500210
- Kauertz, A., Neumann, K., & Haertig, H. (2012). Competence in science education. In B. J. Fraser, K. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education* (pp. 711–721). New York, NY: Springer.
- Kind, P. M. (2003). Praktisk arbeid og naturvitenskapelig allmenndannelse [Practical work and scientific literacy]. In D. Jorde & B. Bugnum (Eds.), *Naturfagdidaktikk. Perspektiver, Forskning, Utvikling* (pp. 226–244). Oslo: Gyldendal akademisk.
- Klafki, W. (2000). Didaktik analysis as the core for preparation of instruction. In I. Westbury, S. Hopmann, & K. Riquarts (Eds.), *Teaching as a reflective practice: The German Didaktik tradition* (pp. 85–108). Mahwah: Lawrence Erlbaum.
- Knain, E. (2005). Definerings og valg av kompetanser—DeSeCo [Defining and selecting competencies—DeSeCo]. *Norsk Pedagogisk Tidsskrift*, 89(1), 125–134.
- Koller, K. T. (2009). *Uteskole = praksis + teori: en studie av muligheter og utfordringer med uteskole i naturfag på videregående trinn 1* [Outdoor education: A study of possibilities and challenges in upper secondary science education] (Master's thesis). Norwegian University of Life Sciences, Ås.
- Kolstø, S. D. (2000). Consensus projects: Teaching science for citizenship. *International Journal of Science Education*, 22(6), 645–664. doi:10.1080/095006900289714
- Kolstø, S. D. (2001). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science Education*, 85(3), 291–310. doi:10.1002/sc.1011

- Krageskov Eriksen, K. (2002). The future of tertiary chemical education—a bildung focus? *HYLE—International Journal for Philosophy of Chemistry*, 8(1), 35–48.
- Laumann, K. (2007). *The missing story—education for sustainable development in Norway* (Master's thesis). University of Oslo, Oslo.
- Lederman, N. G., & Lederman, J. S. (2012). Nature of scientific knowledge and scientific inquiry: Building instructional capacity through professional development. In B. J. Fraser, K. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education* (pp. 335–359). New York, NY: Springer.
- Malone, K. (2008). *Every experience matters: An evidence based research report on the role of learning outside the classroom for children's whole development from birth to eighteen years*. Report commissioned by Farming and Countryside Education for UK Department Children, School and Families, Wollongong, Australia.
- van Marion, P. (2008). Etik, verdier og holdninger [Ethics, values and attitudes]. In P. van Marion & A. Strømme (Eds.), *Biologididaktikk* (pp. 116–137). Kristiansand: Høyskoleforlaget.
- Miller, J. D. (2004). Public understanding of, and attitudes towards, scientific research: What we know and what we need to know. *Public Understanding of Science*, 13(3), 273–294. doi:10.1177/0963662504044908
- Mogensen, F., & Schnack, K. (2010). The action competence approach and the 'new' discourses of education for sustainable development, competence and quality criteria. *Environmental Education Research*, 16(1), 59–74. doi:10.1080/13504620903504032
- Nagel, M. (2005). Constructing apathy: How environmentalism and environmental education may be fostering “learned hopelessness” in children. *Australian Journal of Environmental Education*, 21, 71–80.
- OECD. (2005). *The definition and selection of key competencies—executive summary*. Retrieved January 31, 2013, from <http://www.deseco.admin.ch/bfs/deseco/en/index/02.parsys.43469.downloadList.2296.DownloadFile.tmp/2005.dskcexecutivesummary.en.pdf>
- Orr, D. W. (1992). *Ecological literacy: Education and the transition to a post-modern world*. Albany: State University of New York Press.
- Osborne, J., & Collins, S. (2001). Pupils' views of the role and value of the science curriculum: A focus-group study. *International Journal of Science Education*, 23(5), 441–467. doi:10.1080/09500690010006518
- Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What “ideas-about-science” should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching*, 40(7), 692–720. doi:10.1002/tea.10105
- Osborne, J., & Dillon, J. (2008). *Science education in Europe: Critical reflections*. A report to the Nuffield Foundation. King's College London.
- Östman, L., & Almqvist, J. (2011). What do values and norms have to do with scientific literacy. In C. Linder, L. Östman, D. A. Roberts, P.-O. Wickman, G. Erickson, & A. MacKinnon (Eds.), *Exploring the landscape of scientific literacy* (pp. 160–175). New York, NY: Routledge.
- Palmer, J. A. (1998). *Environmental education in the 21st century—theory, practice, progress and promise*. London: Routledge.
- Pedersen, J. E., & Sadler, T. D. (2012). Science, technology, society, and socioscientific issues—the evolution of a social issues approach to teaching science. In S. Totten & J. E. Pedersen (Eds.), *Educating about social issues in the 20th and 21st centuries* (Vol. 1, pp. 369–390). Charlotte, NC: Information Age.
- Raabs, N. K. (2010). *No child in the Norwegian Woods? A study on education for sustainable development in Norwegian primary schooling* (Master's thesis). University of Oslo, Oslo.
- Rauch, F., & Steiner, R. (2013). Competences for education for sustainable development in teacher education. *Centre for Educational Policy Studies Journal*, 3, 9–24.
- Roberts, D. A. (2011). Competing visions of scientific literacy: The influence of a science curriculum policy image. In C. Linder, L. Östman, D. A. Roberts, P.-O. Wickman, G. Erickson, & A.

- MacKinnon (Eds.), *Exploring the landscape of scientific literacy* (pp. 11–27). New York, NY: Routledge.
- Rudsberg, K., & Öhman, J. (2010). Pluralism in practice—experiences from Swedish evaluation, school development and research. *Environmental Education Research*, 16(1), 95–111. doi:10.1080/13504620903504073
- Rychen, D. S., & Salganik, L. H. (2000). *Definition and selection of key competencies* (pp. 61–73). The INES Compendium (Fourth General Assembly of the OECD Education Indicators programme). Paris: OECD.
- Salganik, L. H., Rychen, D. S., Moser, U., & Konstant, J. W. (1999). *Definition and selection of competencies: Projects on competencies in the OECD context. Analysis of theoretical and conceptual foundations*. Neuchâtel: Swiss Federal Statistical Office (SFSO).
- Sandell, K., & Öhman, J. (2010). Educational potentials of encounters with nature: Reflections from a Swedish outdoor perspective. *Environmental Education Research*, 16(1), 113–132. doi:10.1080/13504620903504065
- Sandell, K., Öhman, J., & Östman, L. (2003). *Education for sustainable development—nature, school and democracy*. Malmö: Studentlitteratur.
- Schmidt, G., & Wolfe, J. (2009). *Climate change: Picturing the science*. New York, NY: W.W. Norton.
- Schreiner, C. (2006). Kunnskapsløft uten bærekraft [Knowledge promotion without sustainability]. *Bedre skole*, (3), 40–47.
- Scott, W. (1996). The environmentally educating teacher: Synthesis of an implementation theory for pre-service courses. *Australian Journal of Environmental Education*, 12, 53–60.
- Shwartz, Y., Ben-Zvi, R., & Hofstein, A. (2006). The use of scientific literacy taxonomy for assessing the development of chemical literacy among high-school students. *Chemistry Education Research and Practice*, 7(4), 203–225. doi:10.1039/b6rp90011a
- Siegel, H. (1988). *Educating reason: Rationality, critical thinking and education*. New York, NY: Routledge.
- Simonneaux, J., & Simonneaux, L. (2012). Educational configurations for teaching environmental socioscientific issues within the perspective of sustainability. *Research in Science Education*, 42(1), 75–94. doi:10.1007/s11165-011-9257-y
- Sinnes, A. T., & Jægstad, K. M. (2011). Utdanning for Bærekraftig Utvikling: To unge realfagslæreres møte med skolehverdagen [Education for sustainable development: Two young science teachers' encounter with school life]. *Norsk Pedagogisk Tidsskrift*, 95(4), 248–259.
- Sjöström, J. (2007). The discourse of chemistry (and beyond). *HYLE—International Journal for Philosophy of Chemistry*, 13(2), 83–97.
- Sleurs, W. (2008). *Competencies for ESD teachers: A framework to integrate ESD in the curriculum of teacher training institutes* (Comenius 2.1 project 118277-CP-1-2004-BE-Comenius-C2.1). Brussels. Retrieved from http://www.unesco.org/env/esd/inf.meeting.docs/EGonInd/8mtg/CSCCT%20Handbook_Extract.pdf
- Stables, A., & Scott, W. (2002). The quest for holism in education for sustainable development. *Environmental Education Research*, 8(1), 53–60. doi:10.1080/13504620120109655
- Sterling, S. (2009). *Sustainable education: Re-visioning learning and change*. Totnes: Green Books.
- Sterling, S. (2010). Living in the Earth—towards an education for our time. *Journal of Education for Sustainable Development*, 4(2), 213–218. doi:10.1177/097340821000400208
- Stuckey, M., Hofstein, A., Mamlok-Naaman, R., & Eilks, I. (2013). The meaning of 'relevance' in science education and its implications for the science curriculum. *Studies in Science Education*, 49(1), 1–34. doi:10.1080/03057267.2013.802463
- Summers, M., Childs, A., & Corney, G. (2005). Education for sustainable development in initial teacher training: Issues for interdisciplinary collaboration. *Environmental Education Research*, 11(5), 623–647. doi:10.1080/13504620500169841
- Tal, T., & Kedmi, Y. (2006). Teaching socioscientific issues: Classroom culture and students' performances. *Cultural Studies of Science Education*, 1(4), 615–644. doi:10.1007/s11422-006-9026-9

- Tilbury, D., & Wortman, D. (2004). *Engaging people in sustainability*. Cambridge: IUCN.
- Tsaparlis, G. (2009). Learning at the macro level: The role of practical work. In J. K. Gilbert & D. F. Treagust (Eds.), *Multiple representations in chemical education* (pp. 109–136). Dordrecht: Springer.
- UNECE. (2011). *Learning for the future: Competences in education for sustainable development*. Utrecht: United Nations Economic Commission for Europe.
- UNESCO. (2005a). *The precautionary principle*. World Commission on the Ethics of Scientific Knowledge and Technology (COMEST). Retrieved from <http://unesdoc.unesco.org/images/0013/001395/139578e.pdf>
- UNESCO. (2005b). *United Nations Decade of Education for Sustainable Development (2005–2014): International Implementation Scheme*.
- UNESCO. (2006). *Framework for the UN DESD International Implementation Scheme*.
- UNESCO. (2012). *Shaping the education of tomorrow: 2012 full-length report on the UN Decade of Education for Sustainable Development*. Paris: Author.
- United Nations. (2002). Resolution 57/254. United Nations Decade of Education for Sustainable Development (57/254). Retrieved from <http://www.un-documents.net/a57r254.htm>
- United Nations Environment Programme. (2012). *Global environment outlook-5: Environment for the future we want*. United Nations Environment Programme (Ed.). Malta: United Nations.
- Voogt, J., & Roblin, N. P. (2012). A comparative analysis of international frameworks for 21st century competences: Implications for national curriculum policies. *Journal of Curriculum Studies*, 44(3), 299–321. doi:10.1080/00220272.2012.668938
- Wagner, T. (2012). *Creating innovators: The making of young people who will change the world*. New York, NY: Scribner.
- Wals, A. E. (2011). Learning our way to sustainability. *Journal of Education for Sustainable Development*, 5(2), 177–186. doi:10.1177/097340821100500208
- Wals, A. E., & Jickling, B. (2002). “Sustainability” in higher education: From doublethink and newspeak to critical thinking and meaningful learning. *International Journal of Sustainability in Higher Education*, 3(3), 221–232. doi:10.1108/14676370210434688
- Ware, S. A. (2001). Teaching chemistry from a societal perspective. *Pure and Applied Chemistry*, 73(7), 1209–1214. doi:10.1351/pac200173071209
- Weinert, F. E. (2001). Concept of competence: A conceptual clarification. In D. Rychen & L. H. Salganik (Eds.), *Defining and selecting key competencies* (pp. 44–65). Seattle, WA: Hogrefe & Huber.
- Wheeler, K. A. (2000). Introduction. In K. A. Wheeler & A. P. Bijur (Eds.), *Education for a sustainable future* (pp. 1–5). New York, NY: Kluwer Academic/Plenum.
- Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science*, 6(2), 203–218.
- World Commission on Environment and Development. (1987). *Our common future*. Oxford: Oxford University Press.
- Zoller, U. (2004). Chemistry and environmental education. *Chemistry Education Research and Practice*, 5(2), 95–97. doi:10.1039/b4rp90014f