Chemistry Education Research and Practice

Accepted Manuscript

Chemistry Education Research and Practice RSCPublishing

ARTICLE

Education for sustainable development in chemistry – Challenges, possibilities and pedagogical models in Finland and elsewhere

Cite this: DOI: 10.1039/x0xx00000x

Received 00th April 2014,
Accepted 00th April 2014

DOI: 10.1039/x0xx00000x

www.rsc.org/

M.K. Juntunen,[a] M.K. Aksela[b],

This article analyses Education for Sustainable Development (ESD) in chemistry by reviewing existing challenges and future possibilities on the levels of the teacher and the student. Pedagogical frameworks that are found eligible in practice are reviewed. Lesson themes that are suitable for implementing socio-scientific issues (SSI) related to ESD into basic chemistry education at schools are discussed. Based on this analysis, three new demonstrative pedagogical models for ESD in chemistry are presented to help guide the work of teachers. The models draw on an interdisciplinary reading of research in the field of SSI-based science education, sustainability science, green chemistry and environmental education. The current state of ESD in Finnish chemistry education is used as an example case throughout the article. Two tasks where future development is required were recognised. The first task concerns supporting chemistry teachers in overcoming the challenges with SSI and ESD they face in their work. The second task is to ensure that students are more often provided with more relevant and flexible chemistry content and studying methods.

Introduction

Sustainability science is a modern field of research, which aims to bridge the natural and social sciences and help find solutions to the conflicts between the disciplines that are threatening our planet (Jerneck et al., 2011). The acute sustainability problems that are facing our planet are related to planetary boundaries. To avoid catastrophic environmental change, humanity must stay within defined planetary boundaries for a range of essential Earth system processes, which include coping with chemical pollution, climate change and loss of biodiversity (Barnosky et al., 2012; Rockström et al., 2009).

In response to growing concern, the concept of green chemistry was introduced in the academia in the 1980s (Centi & Perathoner, 2009). As the concept could easily be associated with political ”green movements”, the concept of sustainable chemistry was introduced in the 1990s. Sustainable chemistry was seen as a more holistic term than green chemistry, but nowadays green chemistry and sustainable chemistry are seen to share similar goals and content according to IUPAC (2013). Both terms denote strategies of sustainable development intent on designing safer chemistry products and processes where hazardous substances are absent or formed only in tiny amounts (Poliakoff et al., 2002).

Sustainable development is usually considered to consist of ecological, economical and socio-cultural aspects, and numerous models of how these aspects relate to each other have been presented (Lozano, 2008). These three aspects often exclude one another in real-world situations. In light of current knowledge it is actually unclear whether it is possible to reach economical growth, environmental health and social justice at the same time. As long as economical growth is tied to the unsustainable use of natural resources and socially unfair contracts, sustainable development cannot be genuinely realised (Bray, 2010; Dryzek, 1997, 132−136; Rohweder, 2008). According to Dryzek (1997), the discourse around sustainable development is powered by human-centeredness, belief in development and belief in combining contradictory aspects. The discourse resembles the discussion regarding ecological modernisation, which emphasises specialists’ power and thus transfers the problems from a societal plane to the business sphere (Laine & Jokinen, 2001, 64; Särkkä, 2011, 85; Åhlberg, 2006). The term ’sustainable development’ is seldom problematized in public discourse. Neither are the multidimensional goals and dimensions of the different sustainability concepts fully defined. Thus, it is obvious that the ethical and practical principles of sustainability have not yet transferred from research into society (Särkkä, 2011; Wolff, 2004). This article answers the call by viewing sustainable development from the perspective of chemistry education.

The practices of sustainability and green chemistry may also be applied to basic school chemistry. Green chemistry is a crucial part of Education for Sustainable Development (ESD) in chemistry (Burmeister, Rauch & Eilks, 2012). According to latest strategies, national curricula and publications in science education research more efforts should be put into bolstering ESD in school science (Inter Academy Panel, 2010; Melén-Paaso, 2006; National Board of Education, 2003, 2004; Osborne & Dillon, 2008; Rocard et al., 2007; UNESCO, 2009; Vassiliou, 2011).

Recently, Burmeister *et al.* (2012) reviewed ESD in chemistry. They suggested that it should include green chemistry practices, socio-scientific chemistry education and the integration of sustainable development into chemistry education strategies. According to them, when schools profile themselves by joining voluntary sustainability programs, the programs should include chemistry-related goals as well. This article extends their view by discussing the challenges and possibilities of ESD in chemistry education on the level of the teacher and the student. The case of Finland is used as an example. Practical pedagogical models and suitable lesson themes are reviewed, discussed and framed against this background.

ESD challenges in basic chemistry education

The role of teachers In Finland teaching ESD in elementary and high school chemistry is in its infancy, even though it has become a basic element of Finnish chemistry teacher education over the last decade (Kaivola, 2007; Uitto & Saloranta, 2010a). Environmental issues, the state of the world and citizens' possibilities for action are rarely discussed during Finnish chemistry lessons (Kärnä, Hakonen & Kuusela, 2012). Science teachers use ethical questions in their teaching less than other subject teachers in Finland (Kuusisto, Tirri & Rissanen, 2012). Many of them feel that in its current state the subject of chemistry is too general in terms of content and distant from the everyday life of students (Aksela & Karjalainen, 2008).

Internationally, science teachers are lacking both theoretical knowledge about ESD and the suitable practical approaches for teaching it (Burmeister, Schmidt-Jacob & Eilks, 2013; Velaquez, Munguia & Sanchez, 2005). Teachers sometimes assume that the term ESD relates to content rather than pedagogy. Furthermore, educators on the university level have reported general uncertainty about the meaning, scope, boundaries, application and limitations of ESD. (Jones, Trier & Richards, 2008) As an example by Sammalisto and Lindhqvist (2008) illustrates, the environmental dimension is often the most common starting point in ESD. When the process of integrating the concept of sustainability into the courses had started from the environmental aspects, university instructors could further develop their courses to also include the economical and socio-cultural dimensions of sustainability.

The field of ESD encompasses numerous interdisciplinary concepts and terms that have to do with knowledge, morals, skills and the effects of actions (Nichols, 2010). A challenge for instructors is to learn how to holistically cover all of the dimensions of sustainability and how to choose pedagogies that are suitable for ESD. When the relationships between the elements of ESD and the possibilities offered by ESD often seem vague even to researchers, it is not surprising they are demanding for chemistry teachers as well.

Socio-scientific issues (SSI) are a crucial part of ESD in chemistry education. In SSI-based education the teaching stems from moral, political and environmental aspects related to science, technology, society and environment one comes across in daily life (Zeidler et al., 2005). The educational practices of socio-scientific chemistry education are described as complex, controversial, up-to-date and relevant to the daily lives of students (Sadler et al., 2007). The main challenges that science teachers face when teaching SSI are presented in Table 1. Teachers may feel that managing a group in open discussion is challenging. The language used in the critical evaluation of issues and argumentation skills is complex. (Millar, 2006) The teachers evade controversial issues in the classroom as they feel the multiple concepts, facts and theories involved are too demanding and time-consuming to handle (Grace, 2006; Reis & Galvao, 2004). Because of a lack of teaching materials on these issues (Grace, 2006), the teachers are forced to undertake extensive interdisciplinary preparative work, which they consider straining (Hofstein et al., 2011). Thus, they mainly use the relevant content that happens to exist in the available science study books. If the teachers present the information to students based only on textbooks, they potentially create a false dichotomy between content and social issues. (Hofstein et al., 2011; Pedersen & Totten, 2001) The teachers struggle with deciding on a suitable socio-scientific issue on their own and finding the time for it in the curriculum. It is counterintuitive to teach SSI when the national exams highlight other kinds of issues. Some teachers view SSI as additional elements that are not considered key elements of the curriculum. (Grace, 2006; Reis & Galvao, 2004) It is possible that the teachers receive no support from their colleagues or from the community outside the school in the interdisciplinary teaching of SSI (Hofstein et al., 2011; Kärnä et al., 2012; Pedersen & Totten, 2001).

Table 1. The challenges science teachers face when teaching socio-scientific issues

Challenge	References
Group management	Millar, 2006
Complex language and theories	Grace, 2006; Millar, 2006; Reis & Galvao, 2004
Lack of teaching materials	Grace, 2006
Amount of preparative work	Hofstein *et al.*, 2011
Finding a suitable socio-scientific issue	Grace, 2006; Reis & Galvao, 2004
Lack of interdisciplinary support from colleagues or community	Hofstein *et al.*, 2011; Kärnä *et al.*, 2012; Pedersen & Totten, 2001
Time limitations due to other curricular goals	Grace, 2006; Reis & Galvao, 2004
Little curricular relevancy and importance	Grace, 2006; Reis & Galvao, 2004

At the practical level, the inclusion of a socio-scientific issue in the chemistry lesson should be more than just a lecture about the issue and the related concerns (Sadler, 2004) – which still seems to be the most common approach in traditional science teaching. Student-centered or inquiry-based science teaching is far less common than the traditional deductive teaching methods, even thought the benefits of these approaches are well-recognised in science education research (Anderson, 2002; Kärnä et al., 2012; Rocard et al., 2007; Smithenry, 2010). The complex dimensions of SSI are not self-evident for students. It is essential to connect people's personal actions and questions to the development of solutions to the issues. The teacher needs to expound on the issues in ESD from different points of view on a level the students can understand. (Newhouse, 1990; Wilmes & Howarth, 2009; Zeidler et al., 2005)

The role of students The challenges faced by students are bound to those faced by science teachers who attempt to teach ESD.

In Finland, dealing with moral issues within science lessons is a foreign concept for most of students. Only few students can connect the importance of skills and knowledge in chemistry to pollution, clean air, water-related issues or other environmental problems. (Tirri et al., 2012) Finnish students struggle the most with practical tasks related to various everyday product materials and they do not connect chemistry to ethics and morals. Additionally, most students do not consider chemistry an interesting or important school subject, which is likely affected by the traditional, deductive and one-dimensional teaching approaches that have dominated Finnish chemistry education. (Kärnä et al., 2012)

Low levels of interest in studying science and chemistry have been recognized internationally as well (Hofstein et al., 2011; Osborne, Simon & Collins, 2003; Rocard et al., 2007). As in Finland, there is an international need to include sustainability aspects in chemistry education more frequently since traditionally it has been uncommon to connect chemistry to ethics and morals (Lymbouridou, 2011).

In order to support more sustainable citizenship and interest in studying science, students need to attain new kinds of skills (for the definition of 'interest' see Krapp & Prenzel, 2011). It is a challenge with which the students need support as they must gradually shift their traditional science learning habits to involve more cross-curricular approaches based on social inquiry. These new learning methods require that the students become more active, use more of their higher order thinking skills and take more responsibility for their own learning (Juntunen & Aksela, 2013b). The 21st century skills that students need to utilise include competencies such as socio-scientific argumentation skills (Sadler, 2004), self-confidence (Tytler, 2012), active citizenship (Zeidler et al., 2005), social skills (Keys & Bryan, 2001) and environmental literacy (Yavez et al., 2009). One of the barriers in developing young people's skills in scientific argumentation has been the lack of opportunities for practicing them within current science classroom activities (Driver et al., 2000). Students have expressed that their own lack of knowledge contributes to their inability to participate in SSI-based discussions (Albe, 2008; Sadler & Zeidler, 2004; Tytler et al., 2001).

As the sustainability issues are complex and multifaceted, it is an educational challenge to try to empower the students to feel competent in participating, making arguments, making changes or performing actions (Paloniemi & Koskinen, 2005). Understanding complex systems, e.g., the life-cycle of a product, is a new and necessary part of basic education (Hogan, 2002). System thinking skills are tools for understanding the reasons, progression, causalities, effects and solutions related to SSI (Wylie et al., 1998; Hogan, 2002). Structuring and linking these socio-scientific elements together again requires higher order thinking skills (Andersson & Krathwohl, 2001).

If the goal in ESD is to steer the dominant culture into a more sustainable direction, it is good to bear in mind that changes in students' attitudes and behaviour are personal and often slow processes (Dwyer et al., 1993; Johnstone & Reid, 1981). Personal values, knowledge, feelings, attitudes, actions, interests, motivations, experiences, learning and the individual's social environment have all been found to influence the students' daily practices (Johnstone & Reid, 1981; Louhimaa, 2002; Uitto & Saloranta, 2010b). In other words, the relationship between sustainable attitudes and sustainable behaviour is complex. Some studies have found a correlation between attitudes and behaviour while others have not (Asunta, 2003; Tung et al., 2002; Tanskanen, 1997). Behaviour is situational, which means that it varies with socio-environmental circumstances (Dwyer et al., 1993; Louhimaa, 2002). The attitudes and behaviour of an individual are in a continuous state of change due to learning, choices and feelings (Asunta, 2003; Kärnä et al., 2012; Tanskanen, 1997). Young people are rarely long-term oriented (Nieswandt, 2007; Krapp & Prenzel, 2011). Consequently, it seems that sustainability issues need to be present often and in the long term in all school subjects. However, it is important to bear in mind that there are also other possible starting points than specific normative attitudinal or behavioural aims. A challenge for ESD in chemistry is to come to the learners' level and ask what their demands or relevancies are in making the change. (Sund & Lysgaard, 2013)

Zsóka *et al.* (2013) divided students into five categories (hedonist, techno-optimist, active environmentalist, familiar and careless) according to their environmental knowledge, attitudes, consumer behaviour and everyday environmental awareness. They point out that there is high variety in the level of commitment and interest among students towards sustainability issues, which should be taken into account when designing courses and curricula for them. In the view of Zsóka *et al.*, today's ESD primarily increases the awareness of already committed students, but may fail to reach the less committed ones. It has been noticed that, at least in Finland, girls are often more concerned about the environment and more willing to improve it than boys (Asunta, 2003; Juntunen & Aksela, 2013b; Kärnä et al., 2012; Tikka, Kuitunen & Tynys, 2000; Uitto et al., 2011). One of the challenges to ESD in chemistry is to find alternative practices that address the issues of normativity or weariness among students so that every student may be engaged (Sund & Lysgaard, 2013).

Possibilities in ESD in chemistry education

The role of teachers Finnish chemistry teachers have called for environmental teaching approaches that are integrative, student-centred and developed collaboratively with students and that relate to the students' daily lives and real world issues (Kärnä et al., 2012). The teachers feel they currently influence the students' environmental attitudes by telling them about environmental issues, behaving as examples and by expressing their opinions (Taskinen, 2008). The teachers themselves are trying to make a difference by saving energy or paper in their work, or making the school atmosphere more sustainable in general (Uitto & Saloranta, 2010a). Despite of these actions, the role of Finnish chemistry teachers as spokespersons for sustainability still needs strengthening. So far they have been supported in Finland with in-service trainings (Aksela & Karjalainen, 2008; Keinonen & Hartikainen, 2011), collaborative development of new teaching approaches (Juntunen & Aksela, 2013) and chemistry teacher education (Kaivola, 2007). There are also possibilities to redesign Finnish course books in chemistry to include more sustainability practices and to highlight SSI and utilise more student-centred pedagogical approaches (Juntunen & Aksela, 2011).

Chemistry teachers want to teach sustainability (Burmeister et al., 2013). Supporting teachers in using new pedagogical models and approaches will improve their motivation to work (Hofstein et al., 2011; Rocard et al., 2007). In-service trainings related to SSI (Feierabend, Jokmin & Eilks, 2011; Lester et al., 2006; Tung et al., 2002) and collaborative development of inquiry-based teaching approaches (Keys & Bryan, 2001) have been used to improve science education outside of Finland as well.

If the teachers aim to develop the students' relationship with nature, significant positive experiences in nature need to occur (Cantell, 2004; Palmer, 1998). These experiences should touch the students' feelings and help them construct knowledge and skills in both personal and socio-scientific real-life contexts. Thus, in the 21st century, chemistry teachers should extend their chemistry lessons out to the field more often. For instance, the students' questions about water or soil could be studied on site in nature (Heimlich & Ardoin, 2008; Littledyke, 2008).

School culture may also affect aspects of the students' environmental awareness, at least to a certain extent (Erdogan, Marcinkowski & Ok, 2009; Lukman et al., 2013). Negev *et al.* (2008) have previously reported that schools appear to have a modest effect on environmental attitudes and behaviour among children, relative to other factors. Even small effects can accumulate as students indirectly influence their families and thus pass on what they have learned (Damerell, Howe & Milner-Gulland, 2013).

The role of students The recognised apathy that students may exhibit toward studying chemistry in Finland (Kärnä et al., 2012) or internationally (Osborne et al., 2003) can be transformed into interest by using topics and teaching methods that are more relevant to the students (Juuti et al., 2009 and Van Aalsvoort, 2004). However, students do not automatically view every SSI-based context as "relevant". Students consider relevance in terms of their perception of the current and future value of the presented information in personal, societal and vocational choices. In other words, science education becomes relevant whenever learning will (positively) affect the student's life. (Hofstein et al., 2011; Stuckey et al., 2013) Environmental and societal issues that are related to the students' daily lives have increased the relevance of chemistry in their minds (Albe, 2008; Juntunen & Aksela, 2013b; Mandler et al., 2012; Marks & Eilks, 2009; Sadler, 2004; Van Aalsvoort, 2004; Yager Lim & Yager, 2006).

From the perspective of the students, SSI-based ESD seems to have multiple benefits. Previous studies on ESD in chemistry have demonstrated, for example, the potential of SSI teaching in improving such higher order cognitive skills as socio-scientific argumentation and evaluation (Burmeister & Eilks, 2012, Feierabend & Eilks, 2011; Juntunen & Aksela, 2013a,b; Zeidler et al., 2005). The benefits are summarized in Table 2. Firstly, this approach supports the students' learning of scientific content knowledge (Bulte et al., 2006; Dori, Tal & Tsaushu, 2003; Klosterman & Sadler, 2010). Socio-scientific issues support the students' skills in applying the knowledge to other similar cases (Yager et al., 2006). Choosing local issues easily connects the science content to the students' daily lives (Sadler, 2004). Secondly, ESD that makes use of SSI increases the students' motivation to study chemistry (Albe, 2008; Mandler et al., 2012; Taskinen, 2008; Sadler, 2004; Yager et al., 2006; Van Aalsvoort, 2004). Thirdly, complex and controversial issues stimulate the intellectual development of the students' moral and ethical thinking (Belland, Glazewski & Richardson, 2011; Oulton et al., 2004; Sadler, 2004; Ratcliffe 1997; Zeidler et al., 2005). Fourthly, students begin to understand how science and society are dependent on one another and how studying chemistry may affect their physical and social environments (Hofstein et al., 2011; Kolstø, 2000; Oulton et al., 2004; Reis & Galvao, 2004; Sadler, 2004; Zeidler et al., 2005).

Table 2. The benefits of ESD that makes use of socio-scientific issues

Benefit	References
Learning of scientific content knowledge and applying it in a societal context	Bulte et al., 2006; Dori et al., 2003; Klosterman & Sadler, 2010; Sadler, 2004; Yager et al., 2006
Improvement in moral and ethical thinking skills	Belland, Glazewski & Richardson, 2011; Oulton et al., 2004; Sadler, 2004; Ratcliffe 1997; Zeidler et al., 2005
Increased motivation of students to study chemistry	Albe, 2008; Mandler et al., 2012; Taskinen, 2008; Sadler, 2004; Yager et al., 2006; Van Aalsvoort, 2004
Improved understanding of the importance of science in society and one's daily life	Hofstein et al., 2011; Kolstø, 2000; Oulton et al., 2004; Reis & Galvao, 2004; Sadler, 2004; Zeidler et al., 2005

The students wish to be heard. In order to reach the full potential of ESD in chemistry, it is important to listen to the students' personal views, beliefs and experiences regarding the issues discussed and study methods used (Cantell, 2004; Palmer, 1998; Sund & Lysgaard, 2013). This further fosters the feelings of self-confidence, optimism and sense of community, which generally speaking increase a person's active care for the environment. If students have feelings of capability and control, they are more likely to start behaving in a more environmentally sound way. (Helve, 1997)

Practical pedagogical models of ESD in chemistry

There seems to be a consensus among researchers that ESD should be based on fostering a holistic world-view. Holistic approaches aim to incorporate sustainability concepts broadly within existing courses and seek for a balance among all sustainability dimensions across the contents of a curriculum (Watson et al., 2013). They consider the three dimensions of sustainable development and socio-scientific actions from local, national and global points of view (Burmeister et al., 2012; Lozano, 2008; Wolff, 2004).

Holistic teaching approaches are rather open-ended and interdisciplinary. They should activate students by stemming from their interests and questions, discuss relevant and topical issues and stay on the students' level of understanding (Bulte et al., 2006; Eloranta, 1995; Mogensen & Schnack, 2010). The relevance of the chosen context is essential from the students' perspective (Dori et al., 2003; Klosterman & Sadler, 2010; Yager et al., 2006). Relevant education contributes to the development of the learners' intellectual skills, promotes the learners' competence for societal participation and addresses their vocational awareness (Stuckey et al., 2013).

Pedagogical research and development of new models needs to be connected to educational philosophy. The most fruitful pedagogical approaches in ESD seem to involve socio-constructivist and critical context-based learning theories. 21st century chemistry teaching with ESD includes new kinds of activities that teach chemistry in context-based social environments – activities that teach students to act for nature based on their own ideas and experiences. Projects integrated into the subject of chemistry offer learners opportunities to develop informed personal competencies without first having to define specific long-term goals, or determine where or how these competencies should be used. The goals set for ESD in chemistry are defined within the chosen context but they are still flexible and under continuous critical evaluation. The role of the teacher can be that of a facilitator or co-participator. The student also has an active role as a learner who constructs new relevant knowledge. (Tani, 2008; Robottom & Hart, 1993; Sund & Lysgaard, 2013)

ESD teaching should avoid restricted and normative approaches, which are simply intended to change the students' attitudes or to coach them to cope in an *already defined future*. Instead, ESD in chemistry should find ways to invite students to democratically participate in individual and global change according to their own ideas and experiences *to create a future*. (Sund & Lysgaard, 2013)

What this learning means for future curricula is an open-ended discussion. In Finland, the restructuring of the National Curriculum for Chemistry Education is currently underway.

In practice, a holistic approach to ESD in chemistry consists of several elements. These are summarized and illustrated in Figure 1. Interdisciplinarity, topical socio-scientific issues involving discussion about solutions, hands-on societal co-operation with stakeholders from outside of the school, social interaction among students, socio-scientific argumentation practices and student-centred and inquiry-based learning methods can, when combined, be used to create a context-based socio-constructivist approach to ESD.

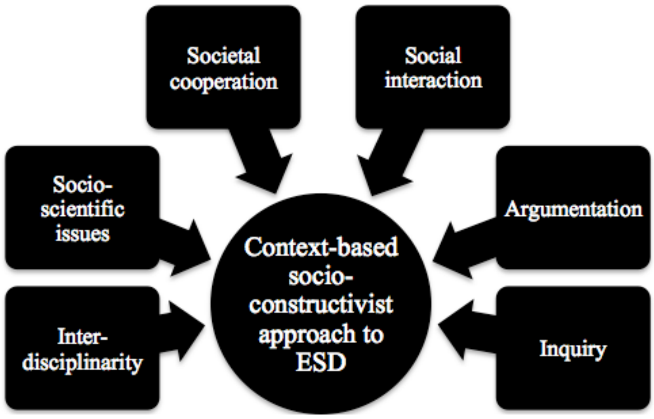

Figure 1. The elements of a context-based, socio-constructivist ESD pedagogy in chemistry

Sustainability issues are usually integrated into chemistry courses in an interdisciplinary manner using SSI (Marks & Eilks, 2009; Tung et al., 2002; Uitto & Saloranta, 2010a; Uitto et al., 2011). Here, student participation is central to helping the students gain feelings of competence and becoming empowered to act (Paloniemi & Koskinen, 2005). SSI teaching approaches are often social and inquiry-based, which, in the light of research, increases student motivation to study and to understand the multifaceted relevance of chemistry content knowledge (Burmeister et al., 2012; Colburn, 2000; Minner et al., 2010). Previously Marks and Eilks (2009) have formulated a framework of the criteria for socio-critical, problem-oriented science teaching. Their framework can be applied to select SSIs for ESD. By answering the following questions when choosing a topic teachers may contribute to developing this framework further:

i) Is the issue *authentic, relevant in the students' point of view and socio-scientifically open-ended, does it allow open debate* and does it *deal with questions about science and technology* (Marks & Eilks, 2009)?
ii) Can I co-operate with other teachers in an *interdisciplinary way* with this issue (Uitto & Saloranta, 2010a)?
iii) What resources do I have in my disposal?
iv) What learning goals do I set in terms of ESD?

v) Am I applying *holistic, student-centred* approaches (Watson et al., 2013)?
vi) How do I tune in the students in the beginning?
vii) How do I best support their appetite to study?
viii) How and by whom is the students' performance evaluated?
ix) Which parts of the approach can I improve on or redesign?

The main features of a student-centred pedagogical strategy of a teacher who wishes to teach SSI-based ESD in chemistry are presented in Figure 2. The process begins with the setting of goals for the chosen topic and teaching methods. These goals, as already mentioned in this article, should involve holistic, co-operative and student-centred approaches (Marks & Eilks, 2009). Both the goals and the methods are formulated on the basis of what is being evaluated. In ESD, the dimensions of student evaluation are – again – complex and multifaceted. It has been suggested that the evaluation of student performance can take into account the following elements: attitudes toward sustainability, behaviour, competence, knowledge (Jensen & Schnack, 1997; Littledyke, 2008; Roth, 1992; Yavez et al., 2007), information seeking skills, critical reflection, argumentation skills, ethical sensitivity, and understanding of different opinions and the nature of science (Oulton et al., 2004).

After the main goals and pedagogical methods have been set, the next step is to activate the students by introducing them to the task and simply letting them participate and create. The task should involve exercises that tackle real-world issues (see, e.g., Adams et al., 2008). Marks and Eilks (2009) suggest starting with a textual approach and problem analysis before moving on to working in a laboratory environment. This is undoubtedly a profoundly fruitful approach. However, a laboratory environment is not a necessary part of studying SSI. For example, in the case of a life-cycle analysis of a freely selected consumer product, the laboratory environment was not a part of the project (Juntunen & Aksela, 2013a).

During the activities related to the socio-scientific issue, those students who need advice can be supported by both the teacher and their classmates. The teacher is also there to give ample personal and formative feedback that is both supportive and empowering. Finally, it is important to catalyse reflection among the students about the task in question, e.g., by means of self-evaluation or reflective discussions. (Applied from Dwyer et al., 1993; Jensen & Snack, 1994) For meta-reflection, Marks and Eilks (2009) suggested utilizing methods that provoke the explication of individual opinions within their framework.

Figure 2. The main features of a student-centred strategy for implementing SSI in ESD from a teacher's perspective (Applied from Dwyer et al., 1993; Jensen & Snack, 1994; Marks & Eilks, 2009)

Open approaches, e.g., group discussions, are practical means for supporting decision-making and argumentation skills, which are highlighted in socio-scientific educational research (Albe, 2008; Sadler, 2011; Tanner, 2009; Wilmes & Howarth, 2009). These open approaches require that the teacher is able to manage uncertainness and seek answers to unexpected questions together with the students, as the answers to socio-scientific questions are typically controversial and constantly changing (Pedretti & Nazir, 2011; Zeider et al., 2005). Students must be provided with real opportunities to interact with society. This may be realised through inquiry by giving them a chance to come up with solutions to a real local or global issue (Burmeister et al., 2012; Mogensen & Schnack, 2009; Salonen, 2010). In practice this means field trips to relevant places, such as non-governmental organisations, communal operators or companies. Visitors from these stakeholders may also be invited to visit the classroom.

Holistic pedagogies of ESD in chemistry have also been previously defined to utilise numerous approaches such as future education, system thinking, critical thinking, participation in decision-making, networking and reflecting on the sense of community (Sadler et al., 2007; Tilbury & Cooke, 2005). In relation to chemistry education, the dimensions of ESD approaches could be categorised to involve

i) experiences and knowledge *in* an environment or place *towards* sustainable development,
ii) skills and knowledge *about* environmental chemistry and sustainable development, and
iii) value education, how to act *for* sustainable development also by using chemistry (applied from Mahruf, Shohel & Howes, 2011; Nordström, 2004; Palmer, 1998).

The phases of teaching ESD in (basic) chemistry in relation to its ecological, economical and socio-cultural dimensions is illustrated in Figure 3. This model is formulated by comparing the educational research on student empowerment in environmental education (Paloniemi & Koskinen, 2005) to the examples about teaching SSI controversies in chemistry lessons. It seems that the teaching process in these examples involves three phases. What is common to previously published chemistry lesson plans is that they all need to introduce the students to the causes and background of an issue first (see, e.g., Burmeister & Eilks, 2012; Eilks, 2008; Eilks, Evlegimenos, Olympios & Valanides, 2003; Marks, Bertram & Eilks, 2008; Marks & Eilks, 2010). Thus, Phase 1 is mainly about the socio-cultural causes and/or history of the issue in question. The socio-cultural, daily-life-bound introduction builds up the necessary background knowledge required for a holistic view. When the socio-cultural context becomes more or less understood by the students, they step into Phase 2. Here, they study the issue from the point of view of chemistry and conduct experimentations. The various experiments help the students to acquire relevant chemistry content knowledge that results in deeper understanding of the issue. This "pure chemistry" phase guides the students to understand the complex issue in question from an ecological viewpoint. Phase 3 seems to involve not only thinking about the socio-cultural and ecological challenges and possibilities of different outcomes and future perspectives, but also exploring the economical views. Contradictory economical aspects have been present, for example, in such student-centred and cooperative approaches as the consumer test method (Burmeister & Eilks, 2012), interest groups' brochures used in discussions (Eilks, 2002), decision making (Eilks et al., 2003), role-playing debate (Juntunen & Aksela, 2014), role-playing of a TV talk show (Marks et al., 2008) and the journalistic news production method (Marks & Eilks, 2010). Thus, Phase 3 highlights the use of higher-order thinking skills (Andersson & Krathwohl, 2001) in value-driven tasks, possibly involving all three dimensions of sustainable development. The interesting questions of Phase 3 seem to be: Could ESD empower the students to see the SSI in question as a set of opportunities for action and as a chance to participate in creating a more sustainable future? Or did the students become disempowered when faced with the challenges and feel that their capabilities are inadequate when sliding towards catastrophic future scenarios? Or something in between? The students' feelings, either those of empowerment or disempowerment, are consequences of Phases 1–3.

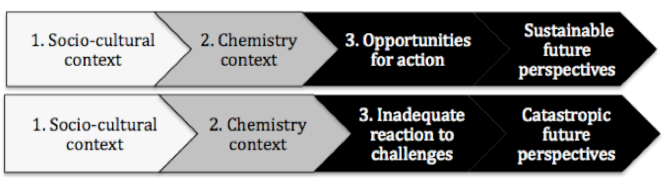

Figure 3. Three-phase presentation of teaching a socio-scientific issue to empower rather than disempower students in ESD in chemistry. Phase 1 includes the socio-cultural causes and background of an issue. Phase 2 presents the main chemistry aspects of the issue in relation to ecology. Phase 3 includes co-operative and value-driven discussions about the opportunities for action and sustainable future perspectives – or the opposite, possibly involving all three dimensions of sustainable development.

Paloniemi and Koskinen (2005) influenced the framing of this model by describing the learning process of environmentally responsible participation. They state that involvement processes, which include experiences and reflection about environmentally responsible behaviour and positive impacts, will create motivation and societal empowerment instead of disempowerment or rejection. Paloniemi and Koskinen (2005) highlight the importance of experiences, working in co-operation, empowerment and capability for action.

Phases similar to those presented in Figure 3 may also be seen in the conceptual framework for socio-critical, problem-oriented science teaching presented by Marks and Eilks (2009). The problem analysis and laboratory working stages in their framework could be included here into Phases 1 and 2. To end the SSI learning session, Marks and Eilks (2009) suggest using discussions and meta-reflection.

Because of the huge socio-scientific challenges facing the world today, it is important for the teacher to inspire hope in the students. The teacher can instil in the students the notion that by acting responsibly on multiple levels of life, it is possible for humans to reach a secure and solidary future. Positive actions can create new ways for people to develop themselves, to connect with nature and to find a meaningful life that is based on sustainable practices, not unsustainable illusions (Salonen, 2010). Only through co-operation can people

i) create better things (incorporate renewable energy into housing purposes or produce less unnecessary things)
ii) learn to live for the better world (switch to eco-labelled electricity, eat more vegetables and walk short distances instead of driving)
iii) change their daily routines for the better (become healthier, save money and relax with immaterial pleasures)

By using the pedagogical means discussed above, ESD in chemistry may touch the students' feelings, empower them and provide them with activating experiences, which may further facilitate a positive personal and cultural change (Paloniemi & Koskinen, 2005).

ESD themes in chemistry education

The chemistry curriculum in Finland includes ESD topics that relate to, for example, air and water problems, which enable the teaching of such issues as climate change, ozone depletion, build-up of small particles and chemicalisation. The curriculum also includes themes related to foodstuffs, materials and resources, the carbon cycle and life-cycle analysis. In relation to ESD, these themes could be bound to a value analysis of different kinds of choices, e.g., recycled and renewable resources versus non-renewable resources in the production of raw materials and products. (National Board of Education, 2003; 2004)

There is a wide range of socio-scientific issues that are easy to integrate into Finnish school chemistry. These issues are related to acute local, national or global sustainability problems, the 12 green chemistry principles, product life-cycle analysis, energy production alternatives, raw materials and future education. The 12 principles of green chemistry include responsibility for preventing the production of waste, using safe substances and conserving materials and energy (Anastas & Warner, 1998). Already, Finnish teachers are sometimes integrating these topics into chemistry lessons (Aksela & Boström, 2012). Matters such as conserving or wasting resources, long-term needs, the quality of products, better choices in daily life and issues related to health are easy to discuss during any regular Finnish chemistry class. All of the topics that relate to socio-scientific issues or sustainable development found in the Finnish National Curriculum for Chemistry can be connected to aspects of the students' daily lives (e.g., housing, food, energy or product life-cycle issues). (Juntunen & Aksela, 2013a; 2014)

A few educational approaches have been published for implementing basic chemistry aspects of SSI into ESD. These SSI approaches have involved student argumentation tasks from social, scientific, economical and ethical points of view related to such topics as product life-cycle analysis (Juntunen & Aksela, 2014), diet issues in relation to potato chips (Marks et al., 2008), artificial musk fragrances in shower gels and their later behaviour in the environment (Marks & Eilks, 2010), debate about bio versus conventional plastics and related consumer tests (Burmeister & Eilks, 2012), and the energy consumption alternatives and challenges of hydrogen cars (Eilks et al., 2003).

Learning about SSI also requires learning basic scientific facts and concepts underlying any issue. This may occur before or after dealing with the other dimensions of sustainability related to the issue. Previously in this article, Figure 3 demonstrated that it is common to start SSI-based education with the socio-cultural daily-life aspects and then move on to the ecological chemistry context. However, the "real" chemistry involved with diverse socio-scientific issues is particularly overwhelming. This is illustrated in Table 2 by using environmental sustainability issues as examples. Themes that are very different from each other are all connected in detecting, analysing, solving and preventing environmental problems (Anastas & Lankey, 2000; Mark & Eilks, 2010). Chemical threats are connected to the health of living creatures, to the types of pollution and the risks in the hydro-, geo-, atmo- and biospheres (Lichtfouse et al., 2005). The issues in question can be studied from the perspectives of the three dimensions of sustainable development, e.g., ethical questions and a socio-cultural perspective on the level of adequate wellbeing for humans, economical sustainability, and the right of every living creature to a healthy environment when preserving biodiversity (Bray, 2010; Salonen, 2010; Tundo et al., 2000).

Table 2. A summary of the chemical aspects of socio-scientific issues for use in ESD in chemistry. These primarily environmental aspects include the effects of chemical substances on health and on living creatures, different pollution types and the diverse risks to ecosystems (Lichtfouse et al., 2005).

Effects on hydro-, geo-, atmo- and biospheres	Heavy metals, organically bound metals, radioactive substances, inorganic gases (CO_x, SO_x, NO_x, N_2O, HFC, PFC, SF_6), asbestos, algae, toxics, photochemically active hydrocarbons, halogenated hydrocarbons (PCB, CFC, PFC…), methane, PAH, dioxins, furans, pesticides, fuel leaks, small particles in the air (VOC, PM, NMVOC), additives in plastics (PBA, phthalates), sewage, cleaning agents, medicines, tastes, smells, colours, noise…
Types of pollution	Point stress (industries, cities), scattered stress (fields, livestock), fallout (burning processes), and natural wash (in acidic conditions, e.g., dilution of aluminium and heavy metals)
Effects on ecosystems	Eutrophication (N, P…), changes in pH, diversity loss (living creatures are sensitive to changes in pH because of pesticides or SO_x, NO_x, NH_3, for example), salting, oxygen loss (H_2S), accumulation of bioaccumulative substances in the food chain and trash (plastics)
Health effects	Acute or chronic, at the level of the individual, species or population
Effects are related to	Death, growth, breeding, hormones, genomes, metabolism of organs, tumours, diseases, harmless carrying of bioaccumulative substances and changes in biodiversity or behaviour

Aspects of environmental chemistry are key content in curricula around the world. They offer manifold opportunities and starting points also for discussion about ethical responsibility, sustainable development and real world issues in the chemistry classroom (Juntunen & Aksela, 2014). The topics of discussion may be, for instance, one of the following, depending on the level of the students (Albe, 2008; Marks et al., 2008; Sadler et al., 2007; Wilmes & Howarth, 2009):

i) Local: Which is a better choice in a restaurant – tap water or bottled water?
ii) National: How to produce energy in Finland?
iii) Global: Why do different countries use different amounts of resources?
iv) Personal: How does a product I use affect the environment?
v) Societal: Are there more responsible choices available?
vi) Ecological: Which substances accumulate in the environment?
vii) Economical: Why does it save money to recycle metals?
viii) Socio-cultural: What does it mean that a product has an eco-certificate?

Other sustainability questions to be considered with the students could be: What are the goals of sustainable development? Is it possible to reach environmental, economical and socio-cultural wellbeing all at the same time? Which technologies has our culture developed to help us reach more sustainable development? Do we believe too optimistically in technological solutions? Should we restrict the power of big corporations? Can we admit that the welfare of the North is built on underpriced and often unethically produced raw materials brought from the South? Do the people in power have a tendency to depreciate and marginalise the citizens who fight for conserving the environment and for sustainable practices? (Kahn, 2008, 10)

Conclusions

This article presented a summary of Education for Sustainable Development in chemistry to support the work of chemistry teachers, chemistry teacher educators and curriculum developers. ESD in chemistry aims to empower citizens, consumers and educators to act on the levels of the individual, the community, the ecosystem and the entire world – based on well-developed and informed personal competencies. Through ESD in chemistry, better habits, practices and skills can extend to all levels of daily life as individuals find relevance in actively participating in the making of a more sustainable world.

This article took the view of Burmeister *et al.* (2012) and extended it to discussing existing challenges and future possibilities for ESD in basic chemistry on the levels of the teacher and the student. Eligible pedagogical models of teaching ESD in chemistry are based on socio-constructivist and critical context-based learning theories, which is demonstrated in this article with the help of three new pedagogical models. The first one summarized the six elements of a holistic approach to ESD in basic chemistry: interdisciplinarity, topical socio-scientific issues, societal co-operation with stakeholders, social interaction among students, socio-scientific argumentation practices and student-centred and inquiry-based learning methods. The second model illustrates the main features of a student-centred pedagogical strategy of a teacher who wishes to teach SSI-based ESD in chemistry. The third model is a new kind of three-phase pedagogical approach to teaching SSI intended to empower rather than disempower students in ESD in chemistry. The teaching of SSI often seems to begin with introducing socio-cultural causes of an issue and then continuing to the chemistry aspects related to ecology. Subsequently, co-operative and value-driven practices are fostered through examples of opportunities for action in sustainable or unsustainable future scenarios, possibly involving all three dimensions of sustainable development. However, the inclusion of economical aspects still seems to be the least discussed dimension in comparison to chemistry aspects bound to ecology and the socio-cultural dimension. Both teachers and students are still facing challenges in implementing new kinds of holistic ESD in chemistry.

Suitable chemistry lesson themes were also discussed. The chemistry related to SSI has endless possibilities in chemistry education. The issues relate to acute local, national or global sustainability problems, the 12 green chemistry principles, product life-cycle analysis, energy production alternatives and raw materials. Similarly to Burmeister *et al.* (2012), the importance of green chemistry practices and socio-scientific chemistry issues are highlighted. Likewise, the integration of sustainable development into "normal" courses and chemistry education strategies and schools profiling themselves by joining sustainability programs that include chemistry elements are also considered very important developmental steps. This article extends the view by summarising possible topics for chemistry education that relate to socio-scientific issues or sustainable development. The aspects include the effects of chemical substances on health and on living creatures, different pollution types and the diverse risks to ecosystems. When teaching, many of these topics can be connected to the students' daily lives and bound to the themes found in the Finnish National Curriculum for Chemistry. These topics also enable imagining possible future scenarios and discussion about the ethical responsibility of science.

Furthermore, two tasks where further development is required are recognised based on the reviewed challenges and possibilities. Both teachers and students need guidance and help in coping with the changing world. The first task is for the curriculum developers and educators of chemistry teachers to support the chemistry teachers in overcoming the multifaceted challenges with SSI and ESD they face in their work. The second task is to ensure that students are more often provided with more personally relevant and flexible chemistry content and studying methods.

To complete these two tasks, in-service training, new collaboratively developed teaching approaches and more holistic chemistry teacher education are required. Chemistry course books should evolve to include more sustainability practices and SSI-based, student-centred pedagogies. ESD in chemistry stems from educating the students in, about and for the environment. The students' participation, capability to act democratically and their feelings of empowerment facilitate a positive personal and cultural change.

In addition to what has been suggested by Burmeister *et al.* (2012), allocating resources to these two tasks would push chemistry education to more efficiently strive toward achieving the most important goal of all – transforming the extensive aims of ESD into actions for a more sustainable world. As the challenges in global sustainability are more complex and multifaceted than ever before in human history, future citizens need new kind of skills so that they can act differently than previous generations – they need to act more responsibly and sustainably as chemists, consumers, parents, voters and decision-makers in this world of complex systems. The realisation of education that supports these skills is also essential in chemistry. There are no excuses why not to do it. With every teacher, student and chemistry lesson, the global aims of sustainability take a step toward reality.

Acknowledgements

We would like to acknowledge the Finnish Cultural Foundation for its financial support.

References

Adams, E., Garon, S., Ward, T., Vanek, D., Marra, N., Jones, D., Henthorn, M. & Striebel, J., (2008), Air toxics under the big sky: A real-world investigation to engage high school science students. *J. Chem. Educ.,* **85**, 221−224.

Aksela, M. & Boström, M., (2012), Supporting students' interest though inquiry-based learning in the context of fuel cells. *Mevlana Int. J. Educ.*, **2**, 53−61.

Aksela, M. & Karjalainen, V., (2008), *Chemistry teaching today: Presence and challenges in Finland.* University of Helsinki, 118. Retrieved from the World Wide Web, May 14, 2013 at http://www.helsinki.fi/kemma/data/KemianOpetusTanaan2008.pdf

Albe, V., (2008), When scientific knowledge, daily life experience, epistemological and social considerations intersect: Students' argumentation in group discussions on a socio-scientific issue. *Res. Sci. Educ.,* **38**, 67–90.

Anastas, P. & Lankey, R., (2000), Life cycle assessment and green chemistry: the yin and yang of industrial ecology. *Green Chem.,* **2**, 289–295.

Anastas, P. & Warner, J., (1998), *Green Chemistry: Theory and Practice* (p. 30). New York: Oxford University Press.

Anderson, R., (2002), Reforming Science Teaching: What Research says about Inquiry. *J. Sci. Teach. Educ.*, **13**, 1−12.

Anderson, L. & Krathwohl, D., (eds.), (2001), *A Taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives.* New York: Longman.

Asunta, T., (2003), *Knowledge of environmental issues: where pupils acquire information and how it affects their attitudes, opinions, and laboratory behavior.* Jyväskylä: University Press.

Barnosky, A., Hadly, E., Bascompte, J., Berlow, E., Brown, J., Fortelius, M., Getz, W., Harte, J., Hastings, A., Marquet, P., Martinez, N., Mooers, A., Roopnarine, P., Vermeij, G., Williams, J., Gillespie, R., Kitzes, J., Marshall, C., Matzke, N., Mindell, D., Revilla, E. & Smith, A., (2012), Approaching a state shift in Earth s biosphere. *Nature*, **486**, 52−58.

Belland, B., Glazewski, K. & Richardson, J., (2011), Problem-based learning and argumentation: testing a scaffolding framework to support middle school students' creation of evidence-based arguments. *Instruct. Sci.*, **39**, 667−694.

Bray, R., (2010), *The importance of controversy: Is education for sustainable development too nice?* Journal of Sustainability Education. Retrieved from the World Wide Web, September 4, 2013 at http://www.jsedimensions.org/wordpress/content/the-importance-of-controversy-is-education- for-sustainable-development-too-nice_2010_05/

Bulte, A., Westbroek, H., de Jong, O. & Pilot, A., (2006), A research approach to designing chemistry education using authentic practices as contexts. *Int. J. Sci. Educ*., **28**, 1063−1086.

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. *Chem. Educ. Res. Pract.,* **13**, 93–102.

Burmeister, M., Rauch, F. & Eilks, I., (2012), Education for Sustainable Development (ESD) and chemistry education. *Chem. Ed. Res. Pract.,* **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. *Chem. Educ. Res. Pract.,* **14**, 169−176.

Cantell, H., (2004), *Handbook of environmental education.* Jyväskylä: PS-kustannus.

Centi, G. & Perathoner, S., (2009), From green to sustainable industrial chemistry (pp. 1−69). In F. Cavani, G. Centi, S. Perathoner and F. Trifiro (eds.), *Sustainable Industrial Chemistry.* Weinheim: Wiley-VCH.

Colburn, A., (2000), An inquiry primer. *Sci. Scope,* **23**, 42–44.

Damerell, P., Howe, C. & Milner-Gulland, E., (2013), Child-orientated environmental education influences adult knowledge and household behaviour. *Env. Res. Letters*, **8**, 1−7.

Dori, Y., Tal, R. & Tsaushu, M., (2003), Teaching biotechnology through case studies – Can we improve higher order thinking skills of nonscience majors? *Science Education*, **87**, 767−793.

Driver, R., Newton, P. & Osborne, J., (2000), Establishing the norms of scientific argumentation in classrooms. *Sci. Educ.,* **84**, 287–312.

Dryzek, J., (1997), *The politics of the earth. Environmental discourses.* Oxford: University Press.

Dwyer, W., Leeming, F., Cobern, M., Porter, B. & Jackson, J., (1993), Critical review of behavioral interventions to preserve the environment: Research since 1980. *Env. Behav.*, **25**, 275−321.

Eilks, I., (2002), Teaching ”biodiesel”: A sociocritical and problem-oriented approach to chemistry teaching, and students' first views on it. *Chem. Educ. Res. Pract. Eur.*, **3**, 67−75.

Eilks, I., Evlogimenos, S., Olympios, C. & Valanides, N., (2003), *Ecologically friendly cars, without emissions. Should they be compulsory?* In J. Holbrook (Ed.), A resource book for teachers in science subjects UNESCO/ICASE 2003. Retrieved from the World Wide Web, October 1, 2008 at http://www.lmnt.org/lmntnytt/Fuel%20Cell2.pdf

Eloranta, V., (1995), *Environmental education in secondary school from teaching materials' perspective* (pp. 34−62). University of Turku. Turku: Painosalama Oy.

Erdogan, M., Marcinkowski, T. & Ok, A., (2009), Content analysis of selected features of K-8 environmental education research studies in Turkey, 1997−2007. *Env. Educ. Res.*, **15**, 525−548.

Feierabend, T. & Eilks, I., (2011), Teaching the societal dimension of chemistry using a socio-critical and problem-oriented lesson plan based on bioethanol usage. *J. Chem. Educ.,* **88**, 1250–1256.

Feierabend, T., Jokmin, S. & Eilks, I., (2011), Chemistry teachers' views on teaching „climate change" – an interview case study from research-orientated learning in teaching education. *Chem. Educ. Res. Pract.,* **12**, 85−91.

Grace, M., (2006), Teaching citizenship through science: socio-scientific issues as an important component of citizenship. *Prospero,* **12**, (3)*,* 42–53.

Heimlich, J. & Ardoin, N., (2008), Understanding behaviour to understand behaviour change: a literature review. *Env. Educ. Res.*, **14**, 215−237.

Helve, H., (1997), *Values, world views and gender* (p. 127). Helsinki: University Press.

Hofstein A., Eilks I. & Bybee R., (2011), Societal issues and their importance for contemporary science education: a pedagogical justification and the state of the art in Israel, Germany and the USA, *Int. J. Sci. Math. Educ.,* **9**, 1459–1483.

Hogan, K., (2002), Small groups' ecological reasoning while making an environmental management decision. *J. Res. Sci. Teach*, **39***,* 641–368.

Inter Academy Panel, (2010), International conference: Taking inquiry − based science education (IBSE) into secondary education. National Science Learning Centre, University of York, UK. Retrieved from the World Wide Web, May 5, 2013 at http://www.allea.org/Content/ALLEA/WG%20Science%20Education/ProgrammeIBSE_YORK.pdf

IUPAC, (2013), *An overview*. IUPAC Green Chemistry Directory. Retrieved from the World Wide Web, July 1, 2013 at http://www.incaweb.org/transit/iupacgcdir/overview.htm

Jensen, B. & Schnack, K., (1997), The action competence approach in environmental education. *Environ. Educ. Res.*, **3**, 163−178.

Jensen, B. & Schnack, K., (1994), Action competence as an educational challenge. *Stud. Educ. Theory Curric.*, **12**, 5−18.

Jerneck, A., Olsson, L., Ness, B., Anderberg, S., Baier, M., Clark, E., Hickler, T., Hornborg, A., Kronsell, A., Lövbrand, E. & Persson, J., (2011), Structuring sustainability science. *Sus. Sci.*, **6**, 69−82.

Johnstone, A. & Reid, N., (1981), Towards a model for attitude change. *Int. J. Sci. Educ.,* **3**, 205−212.

Jones, P., Trier, C. & Richards, J., (2008), Embedding Education for Sustainable Development in higher education: A case study examining common challenges and opportunities for undergraduate programmes. *Int. J. Educ. Res.*, **47**, 341–350.

Juntunen, M. & Aksela, M., (2011), Life-cycle thinking and inquiry-based learning in chemistry education. In M. Aksela, J. Pernaa, & M. Rukajärvi-Saarela (eds.), *International Year of Chemistry: Chemistry for good life* (pp. 96−109). Helsinki: University Press.

Juntunen, M. & Aksela, M., (2013a), Life-cycle thinking and inquiry-based learning in chemistry teaching. *Sci. Educ. Int.,* **24**, 150–166.

Juntunen, M. & Aksela, M., (2013b), Life-cycle thinking in inquiry-Based sustainability education – effects on students' attitudes towards chemistry and environmental literacy. *CEPS J.,* **3**, 157–180.

Juntunen, M. & Aksela, M., (In Press), Improving students' argumentation skills through a product life-cycle analysis project in chemistry education. *Chem. Educ. Res. Pract.*

Juuti, K., Lavonen, J., Uitto, A. & Byman, R., (2009), Science teaching methods preferred by grade 9 students in Finland. *Int. J. Sci. Math. Educ.*, **8**, 611–632.

Kahn, R., (2008), From education for sustainable development to ecopedagogy: Sustaining capitalism or sustaining life? *Green theory & praxis: J. Ecopedag.*, **4**, 1−14.

Kaivola, T., (2007), Sustainable development in teacher education. In T. Kaivola, & L. Rohweder (eds.), *Towards Sustainable Development in Higher Education – Reflections* (pp. 66−73). Helsinki: Publications of Finnish Ministry of Education 2007:6.

Keinonen, T. & Hartikainen, A., (2011), Science in the society – Profiles-initiative supports the development of science education. *Dimensio,* **1**, 17−19.

Keys, C. & Bryan, L., (2001), Co-constructing inquiry-based science with teachers: Essential research for lasting reform. *J. Res. Sci. Teach.*, **38**, 631−645.

Klosterman, M. & Sadler, T., (2010), Multi-level assessment of scientific content knowledge gains associated with socioscientific issues-based instruction. *Int. J. Sci. Educ.*, **32**, 1017−1043.

Kolstø, S., (2000), Consensus projects: teaching science for citizenship. *Int. J. Sci. Educ.*, **22**, 645−664.

Krapp, A. & Prenzel, M., (2011), Research on interest in science: theories, methods, and findings. *Int. J. Sci. Educ.*, **33**, 27−50.

Kuusisto, E., Tirri, K. & Rissanen, I., (2012), Finnish teachers'ethical sensitivity. *Educ. Res. Int.* Retrieved from the World Wide Web, June 11, 2013 at http://downloads.hindawi.com/journals/edu/2012/351879.pdf

Kärnä, P., Hakonen, R. & Kuusela, J., (2012), *Students science skills on basic school at the grade 9 in the year 2011*. Surveillance report on education 2012:2. Ministry of Education. Tampere: University Press Tampere Oy.

Laine, M. & Jokinen, P., (2001), Dimensions of politics. In Haila, Y. & Jokinen, P. (eds.). *Ympäristöpolitiikka. Mikä ympäristö, kenen politiikka.* Tampere: Vastapaino, 47−65.

Lester, B., Ma, L., Lee, O. & Lambert, J., (2006), Social activism in elementary science education: A science, technology, and society approach to teach global warming. *Int. J. Sci. Educ.*, **28**, 315−339.

Lichtfouse, E., Schwarzbauer, J. & Robert, D. (eds.), (2005), *Environmental Chemistry: Green Chemistry and Pollutants in Ecosystems*. Berlin: Springer.

Littledyke, M., (2008), Science education for environmental awareness: approaches to integrating cognitive and affective domains. *Env. Educ. Res.*, **14**, 1−17.

Louhimaa, E., (2002), The social construction of nature, environmental discources and environmentally orientative education. University of Oulu. Retrieved from the World Wide Web, June 17, 2014 at http://jultika.oulu.fi/Record/isbn951-42-6835-0

Lozano, R., (2008), Envisioning sustainability three-dimensionally. *J. Cleaner Production*, **16**, 1838–1846.

Lukman, R., Lozano, R., Vamberger, T. & Krajnc, M., (2013), Addressing the attitudinal gap towards improving the environment: a case study from a primary school in Slovenia. *J. Clean. Prod.*, **48**, 93–100.

Lymbouridou, C., (2011), *Controversial issues in science education for functional scientific literacy: A case study of an implemented curriculum in Cyprus Science classrooms. Dissertation. University of Sheffield.* Retrieved from the World Wide Web, June 18, 2014 at http://etheses.whiterose.ac.uk/1602/2/Lymbouridou%2C_Chrystalla.pdf

Mahruf, M., Shohel, C. & Howes, A., (2011). Models of Education for Sustainable Development and Nonformal Primary Education in Bangladesh. *J. Educ. Sus. Dev.*, **5**, 129.

Mandler, D., Mamlok-Naaman, R., Blonder, R., Yayon, M. & Hofstein, A., (2012), High-school chemistry teaching through environmentally oriented curricula. *Chem. Educ. Res. Pract.*, **13**, 80−92.

Marks, R., Bertram, S. & Eilks, I., (2008), Learning chemistry and beyond with lesson plan on potato crisps, which follows a socio-critical and problem-oriented approach to chemistry lessons – a case study. *Chem. Educ. Res. Pract.*, **9**, 267−276.

Marks, R. & Eilks, I., (2010), Research-based development of a lesson plan on shower gels and musk fragrances following a socio-critical and problem-oriented approach to chemistry teaching. *Chem. Educ. Res. Pract.*, **11**, 129–141.

Marks, R. & Eilks, I., (2009), Promoting scientific literacy using a sociocritical and problem-oriented approach to chemistry teaching: concept, examples, experiences. *Int. J. Env. Sci. Educ*, **4**, 231−245.

Melén-Paaso, M., (2006), *Promoting sustainable development in education: The implementation of Baltic 21E program and the national strategy for the decade of education for sustainable development of UN (2005–2014).* Ministry of Education, 2006:6. Helsinki: University Press.

Millar, R., (2006), Twenty first century science: Insights from the design and implementation of scientific literacy approach in school science. *Int. J. Sci. Educ.*, **28**, 1499−1521.

Minner, D., Levy, A. & Century, J., (2010), Inquiry-based science instruction – What is it and does it matter? Results from a research synthesis year 1984 to 2002. *J. Res. Sci. Teach.*, **47**, 474−496.

Mogensen, F. & Schnack, K., (2010), The action competence approach and the 'new' discourses of education for sustainable development, competence and quality criteria. *Env. Educ. Res.*, **16**, 59−74.

National Board of Education, (2003), *Lukion opetussuunnitelman perusteet 2003.* Helsinki: Finnish National Board of Education. Retrieved from the World Wide Web, June 17, 2014 at http://www.oph.fi/download/47345_lukion_opetussuunnitelman_perusteet_20 03.pdf

National Board of Education, (2004), *Perusopetuksen opetussuunnitelman perusteet 2004.* Helsinki: Finnish National Board of Education. Retrieved from the World Wide Web, June 17, 2014 at http://www02.oph.fi/ops/perusopetus/pops_web.pdf

Negev, M., Sagy, G., Garb, Y., Salzberg, A. & Tal, A., (2008), Evaluating the Environmental Literacy of Israeli Elementary and High School Students. *J. Env. Educ.*, **39**, 3−20.

Newhouse, N., (1990), Implications of attitude and behavior research for environmental conservation. *J. Env. Educ*, **22**, 26−32.

Nichols, B., (2010), Essential Ecoliteracy, or "earth smarts": Defining and validating a pragmatic educational construct based on quality of life. *J. Sus. Educ.*, **1**.

Nieswandt, M., (2007), Student affect and conceptual understanding in learning chemistry. *J. Res. Sci. Teach.,* **44**, 908−937.

Osborne, J., Simon, S. & Collins, S., (2003), Attitudes towards science: a review of the literature and its implications. *Int. J. Sci. Educ.*, **25**, 1049–1079.

Osborne, J. & Dillon, J., (2008), *Science education in Europe: Critical reflections. A Report to the Nuffield Foundation.* Retrieved from the World Wide Web, May 14, 2013 at http://www.fisica.unina.it/traces/attachments/article/149/Nuffield-Foundation-Osborne-Dillon-Science-Education-in-Europe.pdf

Oulton, C., Dillon, J. & Grace, M., (2004), Reconceptualizing the teaching of controversial issues. *Int. J. Sci. Educ.,* **26**, 411–423.

Palmer, J., (1998), *Environmental education in the 21st century*. *Theory, practice, progress and promise.* London: Routledge.

Paloniemi, R. & Koskinen, S., (2005), Environmentally responsible participation as a learning process. *Terra,* **117**, 17−32.

Pedersen, J. & Totten, S., (2001), Beliefs of science teachers toward the teaching of science/technology/social issues: Are we addressing National Standards? *Bulletin Sci. Techn. & Soc.*, **21**, 376−393.

Pedretti, E. & Nazir, J., (2011), Currents in STSE Education: Mapping a Complex Field, 40 Years On. *Sci. Educ.*, **95**, 601–626.

Poliakoff, M., Fitzpatrick, J., Farren, T. & Anastas, P., (2002), Green chemistry: science and politics of change. *Green Chem.*, **297**, 807−810.

Ratcliffe, M., (1997), Pupil decision-making about socio-scientific issues within the science curriculum. *Int. J. Sci. Educ.,* **19***,* 167–182.

Reis, P. & Galvao, C., (2004), The impact of socio-scientific controversies in Portugese natural science teachers' conceptions and practices. *Res. Sci. Educ.*, **34**, 153−171.

Robottom, I. & Hart, P., (1993), *Research in environmental education: Engaging the debate* (p. 599). Geelong, Victoria: Deakin University Press.

Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walberg-Henriksson, H. & Hemmo V., (2007), Science Education Now: A renewed pedagogy for the future of Europe, European Commission Directorate-General for Research Science, Economy and Society. Retrieved from the World Wide Web, May 5, 2011 at http://ec.europa.eu/research/science-society/document_library/pdf_06/report- rocard-on-science-education_en.pdf

Rockström, J., Steffen, K., Noone, Å., Persson, F., Chapin, E., Lambin, T., Lenton, M., Scheffer, Folke, H., Schellnhuber, B., Nykvist, C., De Wit, T., Hughes, S., van der Leeuw, H., Rodhe, S., Sörlin, P., Snyder, R., Costanza, U., Svedin, M., Falkenmark, L., Karlberg, R., Corell, V., Fabry, J., Hansen, D., Walker, B., Liverman, D., Richardson, K., Crutzen, P. & Foley, J., (2009), Planetary boundaries: Exploring the safe operating space for humanity. *Ecol. Soc.,* **14**, 32.

Rohweder, L., (2008), Issues in interpreting in sustainable development Kestävän kehityksen tulkinnallisia ongelmakohtia. (pp. 24−30). In Rohweder, L. & Virtanen, A. (eds.). *Kohti kestävää kehitystä. Pedagoginen lähestymistapa.* Helsinki: Publications of Finnish Ministry of Education 2008:3.

Roth, C., (1992), *Environmental Literacy: Its Roots, Evolution, and Directions in the 1990s*. Massachusetts, Columbus OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education.

Sadler, T., (2004), Informal reasoning regarding socioscientific issues: A critical review of research. *J. Res. Sci. Teach.*, **41**, 513–536.

Sadler, T., (2011), Socio-scientific issues-based education: What we know about science education in the context of SSI. In T. Sadler (ed.) *Socio-scientific issues in classroom: teaching, learning and research* (pp. 355–369) New York: Springer.

Sadler, T., Barab, S. & Scott, B., (2007), What do students gain by engaging in socioscientific inquiry? *Res. Sci. Educ.,* **37**, 371–391.

Sadler, T. & Zeidler, D., (2004), The significance of content knowledge for informal reasoning regarding socioscientific issues: Applying genetics knowledge to genetic engineering issues. *Sci. Educ.,* **89**, 71–93.

Salonen, A., (2010), *Sustainable education as a challenge of a welfare society in the global times.* Helsinki: University Press.

Sammalisto, K. & Lindhqvist, T., (2007), Integration of Sustainability in Higher Education: A Study with International Perspectives. *Innov. High. Educ.*, **32**, 221–233.

Smithenry, D., (2010), Integrating guided inquiry into a traditional chemistry curricular framework. *Int. J. Sci. Educ.*, **32**, 1689−1714.

Stuckey, M., Hofstein, A., Mamlok-Naaman, R. & Eilks, I., (2013), The meaning of 'relevance' in science education and its implications for the science curriculum. *Stud. Sci. Educ.,* **49**, 1−34.

Sund, P. & Lysgaard, J., (2013), Reclaim "Education" in Environmental and Sustainability Education Research. *Sustainability*, **5**, 1598-1616.

Särkkä, M., (2011), *Critical reflection in environmental education*. Masters Thesis. University of Tampere.

Tani, S., (2008), The theoretical background of education for sustainable development (pp. 54−62). In L. Rohweder, & A. Virtanen (eds.). *Kohti kestävää kehitystä. Pedagoginen lähestymistapa.* Helsinki: Publications 2008:3 of Finnish Ministry of Education.

Tanner, K., (2009), Talking to learn: Why biology students should be talking in classrooms and how to make it happen. *Sci. Educ.*, **8**, 89−94.

Tanskanen, E., (1997), *The Finnish and the environment from global perspective* (p. 153). Helsinki: Hakapaino Oy.

Taskinen, M., (2008)., Environmental education and environmental chemistry education in grades 7 – 9. In J. Välisaari, & J. Lundell (eds.), *Days of Chemistry Education: New educational environments and problem-based learning* (pp. 96−109). Helsinki: University Press.

Tikka, P., Kuitunen, M. & Tynys, S., (2000), Effects of educational background on students' attitudes, activity levels, and knowledge concerning the environment. *J. Env. Educ.*, **31**, 12−19.

Tilbury, D. & K. Cooke, (2005), *A National Review of Environmental Education and its Contribution to Sustainability in Australia: Frameworks for Sustainability.* Canberra: Australian Government, Department of the Environment and Heritage & Australian Research Institute in Education for Sustainability.

Tirri, K., Tolppanen, S., Aksela, M. & Kuusisto, E., (2012), A cross-cultural study of gifted students' scientific, societal, and moral questions concerning science, *Educ. Res. Int.*, **2012**, 1−7.

Tundo, P., Anastas, P., Black, D., Breen, J., Collins, T., Memoli, S., Miyamoto, J., Polyakoff, M. & Tumas, W., (2000), Synthetic pathways and processes in green chemistry. Introductory overview. *Pure Appl. Chem.,* **72**, 1207–1228.

Tung, C., Huang, C. & Kawata, C., (2002), The effects of different environmental education programs on the environmental behaviour of seventh-grade students and related factors. *J. Env. Health*, **64**, 24−29.

Tytler, R., (2012), Socio-scientific issues, sustainability and science education. *Res. Sci. Educ.,* **42**, 155–163.

Uitto, A., Juuti, K., Lavonen, J., Byman, R. & Meisalo, V., (2011), Secondary shcool students' interests, attitudes and values concerning school science related to environmental issues in Finland. *Env. Educ. Res.*, **17**, 167−186.

Uitto, A. & Saloranta, S., (2010a), The role of subject teachers in sustainability education (pp. 77−84). In H. Risku-Norja, E. Jeronen, S. Kurppa, M. Mikkola & A. Uitto (eds.), *Ruoka – Oppimisen edellytys ja opetuksen voimavara.* Helsinki: Ruralia-institute.

Uitto, A. & Saloranta, S., (2010b), The realationship between secondary shcool students' environmental and human values, attitudes, interests and motivations. *Procedia Soc. Behav. Sci.*, **9**, 1866−1872.

UNESCO, (2009), *United Nations Decade of Education for Sustainable Development (DESD 2005−2014). Review of Contexts and Structures for Education for sustainable Development Learning for a sustainable world*. Paris: UNESCO.

Van Aalsvoort, J., (2004), Activity theory as a tool to address the problem of chemistry's lack of relevance in secondary school chemical education. *Int. J. Sci. Educ.*, **26**, 1635−1651.

Vassiliou, A., (2011), *Education in Europe: National Policies, Science Practices and research.* European Commission. Retrieved from the World Wide Web, June 13, 2013 at http://eacea.ec.europa.eu/education/eurydice/documents/thematic_reports/133EN.pdf

Velazquez, L., Munguia, N. & Sanchez, M., (2005), Deterring sustainability in higher education institutions: An appraisal of the factors which influence sustainability in higher education institutions. *Int. J. Sus. High. Educ.*, **6**, 383–391.

Watson, M., Lozano, R., Noyes, C. & Rodgers, M., (2013), Assessing curricula contribution to sustainability more holistically: Experiences from the integration of curricula assessment and students' perceptions at the Georgia Institute of Technology. *J. Clean. Prod.*, **61**, 106–116.

Wilmes, S. & Howarth, J., (2009), Using issues-based science in the classroom, *Sci. Teacher,* **76***,* 24–29.

Wolff, L.-A., (2004), Environmental education and sustainable development: From 1960s' to present (pp. 18−29). In H. Cantell, (ed.) *Handbook of environmental education.* Juva: PS-kustannus.

Wylie, J., Sheehy, N., McGuinness, C. & Orhard, G., (1998), Children's thinking about air pollution: a systems theory analysis. *Env. Educ. Res.*, **4**, 117−136.

Yager, S., Lim, G. & Yager, R., (2006), The advantages of an STS approach over a typical textbook dominated approach in middle school science. *School Sci. Math.*, **106**, 248−260.

Yavez, B., Goldman, D. & Peer, S., (2009), Environmental literacy of pre-service teachers in Israel: a comparison between at the onset and end of their studies. *Environ. Educ. Res.*, **15**, 393–415.

Zeidler, D., Sadler, T., Simmons, M. & Howes, E., (2005), Beyond STS: A research-based framework for socio-scientific issues education. *Sci. Educ.*, **89**, 357–376.

Zsóka, Á, Szerényi, Z., Széchy, A. &Kocsis, T., (2013), Greening due to environmental education? Environmental knowledge, attitudes, consumer behaviour and everyday pro-environmental activities of Hungarian high school and university students. *J. Clean. Prod.,* **48**, 126–138.

Åhlberg, M., (2006), Theoretical background of education for sustainable development (pp. 28–36). In T. Kaivola, & L. Rohweder, (eds.).

Korkeakouluopetus kestäväksi. Opas YK:n kestävää kehitystä edistävän koulutuksen vuosikymmentä varten. Publications of Finnish Ministry of Education 2006:4. Helsinki: Ministry of Education.

