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Improving students' argumentation skills through a product life-cycle analysis project in chemistry education

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The aim of the study discussed in this paper was to link existing research about the argumentation skills of students to the teaching of life-cycle analysis (LCA) in order to promote an evidence-based approach to the teaching of and learning about materials used in consumer products. This case-study is part of a larger design research project that focuses on improving education for sustainable development (ESD) in chemistry teaching by means of combining a socio-scientific issue (SSI) and life-cycle analysis with inquiry-based learning. The research question was: How do students (N=8) use scientific, ecological, socio-economical and ethical argumentation in the life-cycle analysis of a product? The research method for this study was content analysis performed on written student answers and an audio recording of a debate. The results show that the students' scientific and ecological argumentation skills with regard to the life-cycles of products were improved during the life-cycle analysis project. The studying also affected, to a lesser extent, the students' ability to form socio-economical and ethical arguments. The type of student-centred and cross-curricular product life-cycle analysis project discussed in this paper is a suitable new method for teaching socio-scientific argumentation to chemistry students at the secondary school level.

Introduction

Challenges in global sustainability are enormous and highly complex (Hogan, 2002; Rockström et al., 2009). These multifaceted challenges are a threat to health, economy, peace and the environment (Barnosky et al., 2012; Governmantal…1998; Jensen & Schnack, 1997; Jerneck et al., 2011; WWF, 2012). Education is critical in achieving a more sustainable future. Education about and for sustainability is needed to improve the capacity of students to address the wide-ranging developmental issues. The research field of education for sustainable development (ESD) in chemistry (Burmeister, Rauch & Eilks, 2012) encompasses numerous concepts and terms that have to do with knowledge, morals, skills and the effects of actions (Nichols, 2010; Palmer, 1998). It seems that in chemistry education, socio-scientific issues (SSI) are a crucial part of ESD. They can provide a context for engaging in informal reasoning and argumentation, which are basic skills for scientifically literate future citizens. When promoting functional scientific literacy in people, it is the controversial scientific issues and dilemmas that affect the intellectual growth of individuals in both personal and societal domains. (Sadler, 2004; Zeidler et al., 2005)

Life-cycle analysis Life-cycle analysis (LCA) is a technical method for evaluating the environmental burden of a product, process or activity by quantifying the net-flows of different chemicals, materials and energy (see e.g., Blackburn & Payne, 2004; Vervaeke, 2012). The assessment of resource use, emissions and the related health impacts creates possibilities for environmental improvements on a product's life-cycle (Anastas & Lankey, 2000). From a chemistry perspective, LCA is a uniting approach: it combines green chemistry (Anastas & Lankey, 2000; Poliakoff et al., 2002), sustainable chemistry (Böschen, Lenoir & Scheringer, 2003) and engineering (Eissen, 2012) – all of which include aspects of science ethics and moral awareness (Burmeister & Eilks, 2012; Zeidler, Sadler & Howes, 2005). It is noteworthy to mention that the concepts of green chemistry and sustainable chemistry are nowadays overlapping and often used in parallel or as synonyms (see e.g. Böschen et al., 2003; Centi & Perathoner, 2009; IUPAC, 2013; OECD, 1999).

Learning about product LCA by conducting a LCA project is a new educational approach presented in our previous studies (Juntunen & Aksela, 2013a,b). The approach is student-centred as the topics touch upon the students' daily lives and are chosen by the students themselves. The open-ended and inquiry-based LCA project is related to the various socio-scientific issues surrounding a product (Colburn, 2000). Through product LCA, the students may practice

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their higher order thinking (Anderson & Krathwohl, 2001) and system thinking skills (Hogan, 2002).

There are only few other papers published that refer to LCA in chemistry education. Most of the life-cycle evaluation techniques intended for educational purposes have been applied at the undergraduate level, and this is also true for the LCA approach. (Allen & Baskhani, 1992; Nair, 1998; Vervaeke, 2012). In comparison to the approach presented in this paper, other published socio-scientific approaches related to ESD are intened to teach the chemistry of different materials, e.g., plastics (Burmeister & Eilks, 2012), shower gels (Marks & Eilks, 2010) and bioethanol (Feirabend & Eilks, 2008). The product LCA teaching approach is in line with the examples of learning about eco-balancing (Eilks, 2002) and consumer-tests (Burmeister & Eilks, 2012) set by these approaches. Water quality experiments, for example, may be broadened into value-based evaluations about the consumption and use of water in the making of products (Bulte, 2006). The issue of climate change has also been studied in order to gauge its potential for focusing students' argumentation and evaluation skills (Feierabend & Eilks, 2010). What is common to all of these ESD approaches is that all of them involve SSI and they have all been reported to support student interest in studying chemistry.

The product LCA project is also a socio-scientific teaching approach. It presents students with an interdisciplinary science topic that is complex, controversial, societal and relevant to their daily lives (Kolstø, 2001; Oulton, Dillon & Grace, 2004; Sadler, 2011). The setting of this approach is very similar to previous socio-critical and problem-oriented approaches to chemistry teaching (Feierabend & Eilks, 2011; Marks & Eilks, 2010). The product LCA approach lacks the laboratory-working phase, which is common for the previously published approaches. Jig-saw (Feierabend & Eilks, 2011) or learning-at-stations (Burmeister & Eilks, 2012) methods are also not used. Another specific feature of the product LCA method is the fact that it is a project-based approach (Juntunen & Aksela, 2013a).

Project-based approach In practice, a product life-cycle analysis is a group investigation into the features of a certain production chain and the raw materials used within it. The approach is case-based and social, which enables the classroom to discuss all kinds of cultural and scientific issues. According to Zeidler et al., (2005) these pedagogical dimensions contribute to a student's personal intellectual development and promote functional scientific literacy.
Project-based LCA is an unconventional approach in chemistry. Because of the complexity of a product LCA project and the open-inquiry pedagogy involved, some initial learning problems may occur – as is also the case with the consumer test method (Burmeister & Eilks, 2012; Colburn, 2000).

Despite of the difficulties, science education research suggests that understanding complex systems is a new and necessary part of basic literature. The science curriculum may be seen as an ideal platform for developing the knowledge and skills required to analyse complex systems (Hogan, 2002). More sustainable citizenship requires chemistry education that enables the students to productively interact in groups around intellectual tasks (Hogan, 2002). The relevant teaching methods often involve cross-curricular inquiry (Colburn, 2000) and peer collaboration (Keys & Bryan, 2001).

Previous studies of ESD and SSI have provoked debate about the potential of SSI in promoting higher order cognitive skills such as competencies in communication and evaluation (Burmeister & Eilks, 2012, Feierabend & Eilks, 2011; Juntunen & Aksela, 2013a,b; Zeidler et al., 2005). Studies about SSI seem to support the notion that SSI are beneficial to the multifaceted skills required for more sustainable citizenship (Tundo et al., 2000). Students in the 21st century require functional scientific literature and skills (Fensham, 2004; Zeidler et al. 2005) that include sustainability competencies (Tytler, 2012), socio-scientific reasoning skills (Sadler, 2004), active citizenship (Zeidler et al., 2005) and environmental literacy (Yavez et al., 2009). All of these are in line with the goals of scientific literacy for all (Holbrook, 2010) and they are all present in this project-based LCA teaching approach. It seems product LCA can serve as an example of a new way to organise chemistry education in the 21st century.

Similarly to other SSI teaching approaches in chemistry (e.g., Eilks, 2002; Feierabend & Eilks, 2011), the LCA project also improves secondary students' attitudes towards chemistry and enhances their environmental thinking skills (Juntunen & Aksela, 2013b). More meaningful studying content and methods are of key importance in changing the students' all-too-negative attitudes towards studying chemistry and steering them into a more positive direction (Juntunen & Aksela, 2013b; Juuti et al., 2009; Osborne, Simon & Collins, 2003; Kärnä et al, 2012). A socio-scientific issue as a context for studying has been documented to support the growth of students' interest, ethical awareness and sensitivity in science learning (Feierabend & Eilks, 2011; Sadler, 2011).

Argumentation This study evaluated students' capabilities to form arguments after they had studied product LCA during chemistry lessons. The aim was to link existing research about argumentation skills (e.g., Jimenez-Aleixandre & Erduran, 2014; Erduran, Simon & Osborne, 2004; Sadler, 2004; Simon, 2008) to learning about materials used in consumer products. The main focus was on analysing individual arguments and smaller pieces of argumentation rather than evaluating entire decision-making processes and patterns of discourse.

The broad theoretical field of both structuring and analysing socio-scientific argumentation is still a work in progress. Students' argumentation and decision-making skills as well as their patterns for coping with socio-scientific debate have been discussed and evaluated widely (see e.g., Aikenhead, 1985; Driver, Newton & Osborne, 2000; Kortland, 1996; Ratcliffe, 1996; Sadler, 2004). In the context of this LCA project, arguments are defined to include claims, data and justifications, which could be supported by evidence and modal qualifiers and be challenged with rebuttals (Erduran, Simon & Osborne, 2004). Argumentation has been suggested to emerge from personal, ethical, societal and scientific dimensions (Kolstø, 2006). It has been identified that students use three types of evidence in their argumentation: informal evidence, evidence from the wider framework of the socio-scientific issue, and scientific evidence (Tytler, Duggan & Gott, 2001; Yang & Anderson, 2003). Inch and Warnick (2002) have described two types of conceptual models for analysing argumentation. Socio-scientific reasoning can include aspects of recognising the complexity of the issue, examining multiple perspectives, accepting on-going inquiry and exhibiting scepticism about potentially biased information (Sadler, Barab & Scott, 2007). Distinction in argument is generally made based on the quality of the argumentation.

In this study, the variability of arguments (Grace, 2009; Liu et al., 2011; Ratcliffe, 1997) was considered in terms of socio-economic, ethical, ecological and scientific aspects (Liu et al., 2010). This is in line with the most common models of sustainable development, which are usually considered to consist of economical, ecological and socio-cultural aspects. However, there are over 300 different visual illustrations or definitions for the concept of sustainable development. (Burmeister et al., 2012; Johnston et al., 2007; Mann, 2011)

Because of the multi-dimensionality of socio-scientific issues and argumentation information, chemistry teachers need support in teaching and evaluating argumentation. There are multiple reasons why chemistry teachers face difficulty in teaching SSI in chemistry classrooms. For instance, they lack materials about suitable issues and feel they are pressed for time due to other ”more relevant” curricular goals. The lack of community support and the complexity of SSI may also hinder them in teaching SSI in chemistry class. (Grace, 2006; Millar, 2006; Reis & Galvao, 2004) These challenges obviously overlap with the challenges teachers face when teaching argumentation skills. Additionally, the teachers are lacking the pedagogical skills to organise argumentative discourse within the classroom (Driver, Newton & Osborne, 2000). They also lack both theoretical knowledge about ESD and the suitable practical approaches (Burmeister et al., 2013). It is crucial to improve teachers' knowledge, awareness, and competence in managing student participation in discussion and argumentation (Driver et al., 2000).

Previous studies have addressed the need for systematic, school-tested material in the teaching of argumentation (e.g., Albe, 2008; Simon, 2008). At the same time, there is a need for new socio-scientific lesson plans that deal with hard-to-define real-world questions. When compared to more traditional, deductive chemistry education, these complex problems train the students to better meet the real world and form arguments regarding socio-scientific issues (Holbrook & Rannikmae, 2007; Jho, Yoon & Kim, 2013; Rockström et al., 2009). Because the personal opinions that teachers have about argumentation affect the learning results, the new teaching material should be collaboratively designed by the teachers to make the material more valued by the teachers themselves (Albe, 2008; Simon, 2008).

One major barrier to developing young people's argumentation skills in science is the lack of opportunities for practicing argumentation within the framework of current science classroom activities (Driver et al., 2000). Students feel that their own lack of knowledge contributes to their inability to participate in SSI discussions (Albe, 2008; Pedretti, 1999; Sadler & Zeidler, 2004; Tytler et al., 2001). If the topic is new and difficult, students express fewer arguments than they do when discussing a more familiar topic (Abi-El-Mona & Abd-El-Khalick, 2006). In general, students have a tendency to make claims without adequate justifications and they do not pay enough attention to opposing positions in the form of counter positions or rebuttals (Sadler, 2004). It is easier for them to form socio-cultural arguments as they touch upon their own opinions and experiences. But if more scientific argumentation is asked for, students need time to search for information or learn the topic first (Osborne, Erduran & Simon, 2004). It is suggested by Simon (2008) that comparing two arguments may help students to realize the importance of justifying their claims. However, naïve epistemological representations often limit students' argumentation, but this may be considered to be a part of their development (Albe, 2008; Driver et al., 2000). Students need more opportunities for practicing argumentation to develop their skills.

The product LCA project addresses the needs discussed above. It is collaboratively designed by chemistry teachers themselves (Juntunen & Aksela, 2013a). The intervention stage of this study enabled the students to practice their argumentation skills on issues relating to the life-cycles of consumer products. The importance of providing ample opportunities to practice justifying claims is previously highlighted by Sadler (2004). It seems that within ESD in chemistry, the most fruitful interventions are the socio-scientific ones, which encourage personal connections between students and the issues discussed, explicitly address the value of justifying claims, and expose the importance of paying attention to contradictory opinions. (Sadler, 2004)

The evaluation of student performance in the product LCA project While chemistry teachers are currently facing difficulties in teaching SSI, simple and practical techniques for evaluating students' argumentation skills are on the way. Wilmes & Howarth (2009) and Holbrook (2005) have discussed simplified and practical techniques for evaluating argumentation in SSI education, which could be used in schools. Feierabend et al. (2012) suggested two instruments for evaluating students' average abilities in argumentation: the quality of the justification with respect to content matter and the complexity of the argument, both of which may be used to represent the quality of argumentation. Within the framework of ESD, Eggert and Bögeholz (2006) characterized students' evaluation competence using four sub-domains, each of which contains four levels. This four-times-four evaluation method seems to be too complex for daily use with large student groups, but more useful for research purposes.

To be of practical use in schools, the student evaluation instruments should stay simple enough from a teacher's perspective. In this study, students' argumentation skills were evaluated from the perspective of their teacher in terms of socio-economic, ethical, ecological and scientific aspects (Liu et al., 2010). This classification seems to be suitable and useful for the purposes of daily evaluation.

The research question According to previous studies conducted by the authors of this article (Juntunen & Aksela, 2013a,b), the product life cycle analysis project is considered to have potential in teaching sustainable development in chemistry and in improving the general argumentation competency of students with regard to socio-scientific issues. The research question of the study discussed in this paper was as follows: How do students use scientific, ecological, socio-economical and ethical argumentation in the life-cycle analysis of products? The results of this study help to expand and improve the evaluation of student performance in the project-based teaching of product life-cycle analysis, especially with regard to chemistry education.

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Methods

This study is a qualitative case-study and part of a larger educational (see Juntunen & Aksela, 2013a,b) design research project (Edelson, 2002). The case-study method was selected because it is suitable for making a deeper analysis of a certain test group in a framed context. The goal was to understand the context: the quality of argumentation in an intervention, which in this case took the form of the product LCA project. It was not the intention to statistically generalise anything (Cohen, 2007).

Participants The eight ethnically homogenous participants were 15-year-old students from a rural Finnish secondary school. This group of students was selected because one of the authors of the research project was a chemistry teacher of the group at the time. This type of a setting is suitable for educational intervention case-studies (Cohen, 2007). One of the authors collected the research data during the year 2013. The students completed the intervention in 6 weeks, which was also the time period focused on in the study (this is the time period between the preliminary task and the final essay).

Intervention and data collection tools Various tools were used to assess the students' level of argumentation. To clarify and illustrate the structure of the data collection process, all the tasks the students performed are presented in Table 1 and explained below in detail. After the LCA project intervention was completed, it took two additional weeks to perform the post-project tasks because the students only had two chemistry lessons per week. The schedule was dependent on these curricular time limitations and also on the teacher's ability to organize the tasks within the weekly school routine.

Table 1. Outline of the study

Week	Activity	Time taken to perform the task
1	Preparatory task	15 min
1	Pre-task	20 min
2–4	Intervention	10–15 hours
4	Post-task	30 min
5	Debate	20 min
5–6	Writing an essay	2–3 hours

As a preparatory task for the product LCA project, the students were brought together to brainstorm and come up with various "global issues". The teachers helped to ensure that all of the following categories of socio-scientific argumentation were to be covered: scientific, ecological, ethical and socio-economic (Liu et al., 2010). The teachers did not tell the students about the categories at any stage of the study.

Immediately after the preparatory task, the students received a socio-scientific story on which they had to make a decision and form arguments regarding an imaginary situation. The story was titled: "Should she buy it or not?" (see Appendix 1). The story was designed by using questions from Baytelman and Constantinou (2014). This was the "pre-argumentation task" looked at in this study. The analysis of the task focused on the quality of the arguments. The answers of the students were evaluated on an individual level in terms of whether they made an argument that fit into one of the above-mentioned categories: socio-economic, ethical, ecological or scientific (Liu et al., 2010).

Students then participated in the intervention – the product LCA project (for details, see Juntunen & Aksela, 2013b). The intervention took the form of project work based on the inquiry-based and student-centred social teaching model (see Colburn, 2000; Joyce & Weil, 1986). The aim of the project was to have the students consider the pros and cons of the life-cycle of a product in small teams. The students chose the product their team would focus on based on their own interests. During the project, the students were involved with setting their own research questions, searching for information, discussing their findings in teams, reviewing the work of other teams, and presenting their results. The students collected data about their product's raw materials, manufacturing processes and material usage, as well as recycling and waste management.

The key element of the project-based LCA approach is that its contents are based on the students' own interests. In cases where the team of students was particularly capable, their investigations included such elements as precise information or estimates about the product's lifespan, footprints, health effects and environmental impacts. Their investigations could also include discussions about a product's ecological backpack (material input per service unit) or a consumer's ecological footprint, water footprint or carbon footprint (Bulte, 2006; Mattila & Antikainen, 2010). The chemistry-related solutions to recycling products or raw materials may be brainstormed with the students. Here, ethical questions may also be discussed (e.g., using water to make different kinds of consumer products).

Depending on the teacher, the student group and their chosen product, the intervention lasted approximately 10–15 hours over a period of 2–4 weeks. The time it took to complete the intervention is an estimate, because the students also had the chance to work on the project at home and they worked at different speeds. The content of the work was up to the students themselves; this way they learned to take responsibility for their own learning. Throughout the project, the role of the teacher was that of a facilitator, supporting the students with ideas whenever they needed help or encouragement (Driver et al., 1994). After the project was concluded, the students had an opportunity to engage in a role-playing debate (Albe, 2008; Feierabend & Eilks, 2011) about their views regarding the usefulness of the products, the responsibilities involved and the individual's possibilities for action. The structure of the intervention was as follows:

1. Familiarising students with the life-cycle topic with, for example, a video or discussion

2. *Students in small groups…*

 …come up with general questions about life-cycle analysis

 …choose a product to investigate based on their own interests

 …come up with questions about their products' life-cycle and select research questions

 …search for information from sources that interest them

 …collect answers to their research questions onto a platform of their choice

 ...act as opponents to the work of another group and at the same time get tips from their work

 …improve their own work based on the tips received from the work of the other group

 …prepare a presentation

 …prepare two questions to ask their opponent group at the presentation event

3. Presentations where the opponent group poses at least two questions to the presenting group. The parents of the students as well as other involved parties are invited to attend the presentations.

4. Summary discussions and/or a role-playing debate regarding the project, user consumption and individual's possibilities for action

After the product LCA project was concluded, the students practised argumentation in the same small teams they were divided into during the project. Now they were posed questions related to the sustainability aspects of their product. The students' discussions were supported by open-ended statements (Erduran, 2013) and questions, which were designed using their Finnish chemistry study book's argumentation form (Mikkola, Luukka & Ahonen, 2006). This task was named the "post-argumentation task" and its format is presented in Appendix 2. The analysis of this task focused on the quality of arguments on a team level. The teams' answers were evaluated by considering whether the team made an argument that fit in to any of the following categories: socio-economic, ethical, ecological and scientific (Liu et al., 2010).

A 20 minutes-long debate was also organised where the students played different roles. The roles that the six participating students played (2 students were absent) were: an environmental researcher, a chemist, a consumer-representative, a shop owner, a financial minister and a representative of the discussed product's safety organisation. They had to form arguments regarding a story about a DVD presented in Appendix 3. Audio of the debate was recorded in the classroom for later content analysis. The total number of arguments made by the entire student group in each category (socio-economic, ethical, ecological and scientific) was counted (Liu et al., 2010).

Finally, the students individually wrote an essay about the project as part of their Finnish language classes. The title of the essay was: "Thoughts about the life-cycle of my product". The students were encouraged to write personal opinions, future perspectives and sustainability ideas related to their product. The analysis of the essays also focused on the quality of arguments. Each essay was evaluated on an individual level by considering whether the student made an argument that fit into any of the following categories: socio-economic, ethical, ecological and scientific (Liu et al., 2010).

Data analysis The analysis of the qualitative data was conducted by adapting the categories reported by Liu et al. (2010) to fully describe the range of the participants' responses. The categories and relevant key concepts as well as example quotes are listed in Table 2. The socio-economic category relates to costs or benefits to a person or a society (e.g., in the form of taxes or revenues). The ethical category relates to values or personal opinions about aesthetics or the future (e.g., what is right, what is wrong and what should be changed). The ecological category includes the effects on the ecosystem and ecological human actions (e.g., recycling). The scientific category includes arguments about natural resources, technologies, energy, materials and pollution. To support the interpretations made, some direct quotes from the transcriptions are also provided in Table 2. As the interviews, transcriptions and the analysis are in Finnish, the direct quotes are translated from Finnish into English by the authors.

Table 2. Key concepts and example quotes of the four categories (Liu *et al*., 2010) used in the content analysis of the data.

Category	Key concepts	Example quote
Socio-economic	Costs or benefits	"The products must break so that the state gets more tax-revenues as people buy new ones." "This costs only a few cents, but a more sustainable option costs hundreds of times more."
Ethical	Opinions related to values, aesthetics or the future	"Using child-labour is wide-spread and I think it should be reduced." "We should innovate something better on that issue."
Ecological	Effect on ecosystems, eco-friendlier products and lifestyle	"Irrigation may cause local water resources to dry and make the ground more salty." "The seller should sell something more sustainable, and sell more environmentally friendly products."
Scientific	Natural resources, technologies, energy, materials	"Then you need the surveillance cameras, which consume lots of natural resources, you need to produce electricity for them, probably using uranium…" "So many products mean mining, oil-drilling and transportation that when combined it equals to so much pollution."

Validity, reliability and ethical considerations This case-study is a part of a larger design research project (Edelson, 2002). The intervention – the product LCA project – was collaboratively designed and developed with chemistry teachers (Juntunen & Aksela, 2013a). The first author of this study was primarily responsible for the implementation of the intervention in the chemistry classroom. The same setting has been used previously in similar studies (e.g. Eilks, 2002; Juntunen & Aksela, 2013b).

Where this particular study was concerned, the first ethical challenge was the vested interest of the first author with regard to the intervention. Her involvement with the course might detract from the internal validity of the study as she was involved in all stages of the design process. On the other hand, the author had thus the opportunity to collect data over an extended period of time. When addressing the reliability issue, previously suggested measures for conducting educational design research (McKenney, Nieeven & Van den Akker, 2006; Plomp, 2009) were taken into account throughout the project to lessen the chance of a skewed interpretation of the data and to compensate for the potential bias stemming from the dual role of the author as an implementer and evaluator. These measures were:

i) Systematic documentation of the research design and analysis process was carried out throughout the research project.

ii) Contextual frameworks and critical reflections were based on extensive review of literature.

iii) Previous interventions were used as examples in the design of the project.

iv) Triangulation of the data collection methods.

v) Full, context-rich descriptions of the context, design process and research results were provided.

One of the weaknesses of the case-study method is often the subjectivity of the results (Cohen, 2007). To increase the objectivity of the results, both research tool and researcher triangulation were used. The four different research tools were used to analyse the quality of the argumentation and to obtain valid results. The study methods were based on counting the exact amount of defined structural elements. To validate the results further, another researcher independently conducted a similar content analysis on the same data. A consensus of the results of the analyses is presented in this article.

Another ethical challenge lies in studying the students' argumentation. In the beginning of the project, the students were given a realistic view of the research project and the dual-role of their teacher. The research data was based on the compulsory learning tasks the students completed during the product LCA project, which formed a part of their chemistry course. The students were encouraged to form all kinds of arguments they could possibly imagine. The data included four written exercises, which were also part of everyone's personal course evaluation and analysed after the project. The anonymity of the students was ensured with cautious and systematic data management. This caution also extended to data storage. The research data was not personally sensitive.

The group of participants in this study was a rather small one, so the generalisation of the results is impossible. The conclusions are not statistically representative. However, in the context of the research problem, representative conclusions may be drawn about how students use argumentation with regard to consumer products and their life-cycles.

Results

The group intervention with eight students resulted in the life-cycle analyses of a DVD, a sheet of copy paper, a pair of jeans and a lock. These analyses took the form of posters or electronic presentations. An example of a poster is presented in Picture 1. This example poster includes all the main phases of a life-cycle (Fava et al., 1991) for a pair of jeans. It begins from the cultivation of the cotton and moves on to the manufacture of the raw materials. Then comes the sewing of the product, selling of the product, washing of the product and then, finally, the product ends up at the flea market and is ultimately placed in the most common disposal site – a dump. Between the different phases, transportation of the product takes place. At each phase of the life-cycle, the students were guided to illustrate the inputs and outputs of that phase in some manner. The pictured example is a typical result of this kind of project and it shows the level that most students reach. The students' works included various kinds of information and data, which the students proudly presented to their parents in an evening gala at the end of the project.

Picture 1. A life-cycle analysis of jeans made by two secondary school students in the chemistry classroom

The arguments presented by the students in the pre-argumentation and post-argumentation tasks and the essay were analysed on an individual level in terms of how they fit into the four categories defined in the previous chapter. The results show that all students were able to make socio-economic arguments both before and after the project. The LCA project was shown to have an impact on the students' scientific and ecological argumentation skills. Before the intervention, only two students wrote ecological arguments and one student came up with a scientific argument. After the intervention all of the students wrote both kinds of arguments. According to the results, four of the students were capable of ethical argumentation in the pre-argumentation task, but only two presented ethical arguments in the post-argumentation task. However, ethical argumentation was the most common argument type used in the essay where six students expressed ethical thoughts related to their product. Only one student did not make any ethical statements during any of the study tasks. The results are displayed in Figure 1.

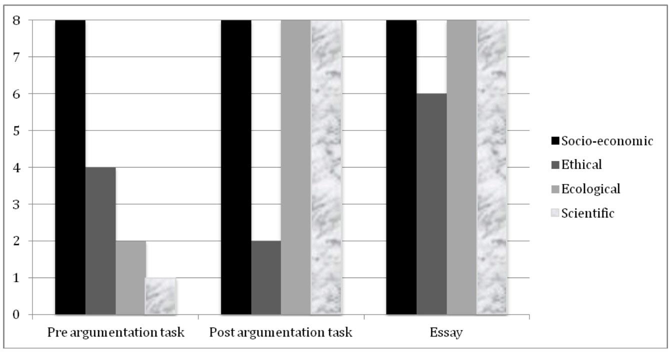

Figure 1. The number of students (N=8) making arguments in each of the category after the different tasks (Liu *et al.*, 2010).

The number of arguments presented during the role-playing debate that fell into each of the four categories was counted in order to understand the qualitative distribution of argumentation in the whole classroom. The results show that socio-economical and scientific arguments were most common: there were 16 arguments that fit into those categories presented during the 20 minute role-playing debate. Ecological arguments were almost as common: there were 14 of them. However, ethical arguments were rare: only 4 ethical arguments were expressed. The results are shown in Figure 2.

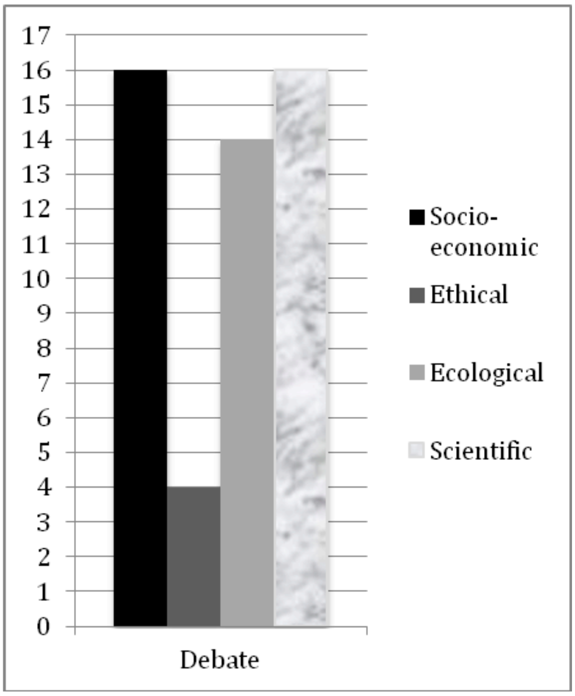

Figure 2. Number of arguments presented during the role-playing debate in each of the four categories (Liu *et al.*, 2010).

Discussion and implications

This case-study implies that this new secondary school chemistry approach – the product LCA project – is a suitable method for teaching students socio-scientific argumentation skills. The socio-scientific contexts are well-known forums for working on argumentation skills (e.g., Feierabend & Eilks, 2011; Sadler, 2004), but simply being exposed to SSI does not make students better at reasoning or at analysing arguments. The promotion of argumentation skills is a difficult and multi-dimensional educational goal (Albe, 2008; Sadler, 2004).

It was not surprising the intervention fostered the students' scientific and ecological reasoning skills regarding the life-cycles of various products. During the product LCA project the students generated a synthesis from information they considered relevant. They socially constructed context-based knowledge and formulated personal connections between themselves and the issues discussed (Sadler, 2004). Improved content knowledge has been previously linked to increases in informal reasoning capabilities (Sadler & Zeidler, 2004). Socio-scientific teaching has led to an increase in the number of arguments, but the quality of these arguments is low (Feierabend et al., 2012). While this paper is not the first one to argue that a socio-scientific approach to teaching may foster students' argumentation skills, the results of this case-study support the usefulness of the product LCA approach in practicing argumentation in general, and especially in practicing argumentation in chemistry.

Generally in ESD, students tend to exclude scientific knowledge from their personal knowledge (Albe, 2008; Sadler, 2004; Solomon, 1992; Tytler, Duggan & Gott, 2001; Yang & Anderson, 2003). It is therefore interesting that after the intervention all of the participating students expressed scientific and ecological arguments. It seems that the knowledge the students gained during the project helped them form arguments from scientific and ecological points of view in particular.

The students first judged the issues related to their chosen product by simply using socio-economic arguments. They all expressed socio-economic arguments both before and after the intervention. Socio-economic argumentation seemed to be the form of argumentation most connected to the students' daily lives, which corroborates the findings of Osborne et al. (2004) and Flemming (1986). Socio-economical argumentation is rather in line with the rationalistic reasoning culture that has typically been fostered and honoured in science classrooms (Zeidler et al., 2005).

When viewing the results from an ESD perspective, ethical argumentation could have been more prominent. All of the students seemed somehow restricted or at least shy in expressing moral arguments. Ethical dimensions are still new and uncommon in Finnish chemistry lessons (Kärnä et al., 2012). If students do not consider ethics to be a part of a chemistry lesson (and something a teacher wants to hear from them), it surely affects the way students engage in ethical reflection.

Students need support in connecting product-related issues and moral perspectives more deeply to the various SSI frameworks in chemistry. Similar notions are recognised by Zeidler et al. (2005). In the context of product life-cycle analysis, the moral arguments were more present in the individual essay than in the group tasks (the post-argumentation task and the role-playing debate). It might be that ethical perspectives easily become too personal, which might explain why the students avoided expressing their ethical thoughts during the group activities. It seems the students need encouragement in expressing their emerging moral views to other students.

It may be concluded that within the context of product LCA, there is no need for more practise in simply expressing socio-economic arguments. Instead, teachers should focus on developing the quality of the socio-economical argumentation prevalent among their students and take those ideas in a more ethical direction, for example. As a result of the product LCA project, the argumentation quality of the participating group became more varied. The students who were exposed to the project might well be more likely to consider not only the socio-economic aspects, but also the moral, ecological and scientific aspects in their future studies and daily lives (Zeidler et al, 2005).

In this study, the students were not looking for a consensus. Therefore, one limitation of this study lies in the goals set for the argumentation tasks. In contexts where students value other perspectives as a means of refining and elaborating their understanding of science, they construct deeper knowledge. Instead of a competitive debate, the students could be engaged in two-sided reasoning and made to look for a consensus together when constructing knowledge. This would help the students to form more sophisticated arguments (Garcia-Mila, Gilabert, Erduran & Felton, 2013). Our analysis of the different argument categories offers only one lens through which argument quality may be viewed.

Students' argumentation skills are generally not well-developed when it comes to evaluating socio-scientific information (Feierabend et al., 2012). Albe (2008) suggested that there is a complex interrelationship between the contextual, epistemological and social factors that influence students' argumentation processes when they are dealing with a controversial socio-scientific issue. This is why the different dimensions of knowledge (Krathwohl, 2002) or levels of reasoning (Sadler, 2011) in the presented arguments were not analysed in this study, but instead the focus was placed on the categories and the number of arguments.

It is very demanding in social and epistemological terms for students to elaborate on arguments and apply the knowledge gained in the product LCA project in a role-play activity. It seems that at a secondary school level it is important that the teacher encouragingly pays attention and tries to notice when the students try to form arguments. With regard to the complex field of SSI, the crucial facilitator to more well-developed and self-confident argumentation is a teacher who values all the emerging arguments the students are trying to form. Flaws in informal reasoning when dealing with complex topics are common among students as well as among adults (Driver et al., 2000; Sadler, 2004). For instance, Zeidler and Sadler (2004) found no evidence that individuals with different levels of content knowledge relied on different modes of SSI reasoning (rationalistic, emotive or intuitive). As other authors have stated, naïve epistemological representations often limit argumentation (Albe, 2008).

This study supports previous evidence (e.g., Albe, 2008; Feierabend et al., 2012) for the necessity of creating science education practices to improve students' overall argumentation and decision-making skills. Subsequent studies should address the students' argumentation skills outside of the classroom. How do the students talk about products after the product LCA project has been completed? We have already found (2013b) that at least some of the participating students do consider their material consumption differently after the project, at least for a while. Those students who are able to carefully consider SSI and make reflective decisions regarding those issues have acquired an improved degree of functional scientific literacy (Zeidler et al., 2005).

Future citizens must gain the skills to act responsibly and sustainably as chemists, consumers, parents, voters and decision-makers in this world of complex systems (Hogan, 2002). Through similar SSI practices as those presented in this article and in previous studies (see Bulte 2006; Eilks, 2002; Feirabend & Eilks, 2008; Marks & Eilks, 2010), the crucial education about and for sustainable development can be realised (Burmeister et al., 2012). Socio-scientific issues can provide means for chemistry teachers to stimulate the intellectual and social growth of their students – a goal which is not easy to achieve (Albe, 2008). In addition to the LCA project, there are several options for socio-scientific chemistry education, including business games (Feierabend and Eilks, 2011), consumer tests (Burmeister & Eilks, 2012) and pedagogies such as the journalist method, which imitates work in the press or TV (Marks and Eilks, 2010; Marks et al., 2010). Future citizens need to have skills in positive skepticism concerning the ontological status of scientific knowledge in decision-making.

Future studies should aim to find other effective means for conducting ESD in chemistry. There appears to be a lack of such efforts thus far (Burmeister et al., 2012). Could chemistry teaching be taken outdoors more often? Which topics related to sustainability does today's chemistry teaching cover and which are left uncovered? Which socio-scientific issues should be taught at which age? The best practices should be shared among chemistry teachers. Understanding all of this is crucial when improving ESD in 21st century chemistry classrooms and when steering the sustainable development of our society at large.

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Appendices

Appendix 1. Should she buy it or not?

Nina wanted to buy a new bag for school because she felt that the old one was unfashionable and raggedy. A new bag made of cotton cost Nina only 15 euros because Nina's brother works in a bag shop. Finnish people are among the richest 1/5 of the world's people and thus belong to the population who consume 4/5 of the food, material and energy resources of the world.

Meanwhile Amiz, who belongs to the poorest fifth of the world's people, is sewing a school bag in India. His working day is 14 hours long. His whole family works at the same factory; otherwise they would not have money to buy enough food. They get food and water from work, plus a salary of 1.5 euros per day. The factory rented the fields owned by Amiz's family to grow cotton. With the rent money they get from their fields, the family was able to send Amiz's sister to a school in Mumbai.

1. Should Nina buy the bag or not?
2. How do you justify your opinion to your friend who disagrees?
3. How is your disagreeing friend justifying his/her arguments?
4. Give rebuttals to you friend's thoughts. How do you argue against his/her views?

Appendix 2. Environmental aspects related to the life-cycle analysis of our product. Continue the sentences or create your own sentences!

The environmentally challenging aspects of our product's life-cycle are…
This is because…

Suggestions on how to improve those aspects:

The product is already ecologically efficient in terms of…

You should buy the product because…
if…

You should not buy the product because…
if…
unless…

The life-cycle of the product will become more sustainable in the future
when…
if…

Appendix 3. The story for the debate

John wanted to spend an evening with his girlfriend Anna. He decided to buy her a new DVD movie as a surprise. When he got home and gave the movie to Anna, she did not want to see the movie. Instead, she wanted to go out for a walk with their dog. So the new DVD was just left unwatched on the floor, even though making it had consumed natural resources. During the night, the dog bit the DVD and broke it. What should have been done differently?