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Science Education and Education for Sustainable Development – Justifications, Models, Practices and Perspectives

Ingo Eilks
University of Bremen, GERMANY

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The year 2014 marks the end of the United Nations Decade of Education for Sustainable Development (ESD). All educational domains and levels, including primary and secondary science education, have been working to contribute to education enabling younger generations to become responsible citizens and promote sustainable development in our world. This paper gives insights into some theoretical foundations of the UN Decade for ESD. Different models of implementing ESD in the teaching of science and technology are presented and illustrated by various case studies, which were developed by the University of Bremen chemistry education group. These examples and the corresponding evaluation case studies show that thoroughly combining the ESD framework with science teaching that follows a socio-scientific issues-based approach to education has great potential for helping students develop many general educational skills. It also opens a path to a more balanced view of science in its societal and professional context. This allows career orientation both in and beyond science and engineering.

Keywords: science education, sustainability, education for sustainable development, socio-scientific issues-based science education, educational reform, teacher education

INTRODUCTION

Skyrocketing industrial development led Western societies in the 1970s to begin necessary discussions about the limits of growth facing industry, population and resource consumption (Meadows, Meadows & Randers, 1972). This process was inspired by a growing awareness of mankind's responsibility to present future generations with an intact environment, thus providing them with chances for future prosperity and growth. Starting from the ideas in the Limits of Growth report published by the Club of Rome (Meadows et al., 1972), a contemporary understanding of sustainable development began to develop. The discussions led to the work of the Brundtland Commission, which defined sustainable development as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs." (UN, 1987)

In the Agenda 21 (UNCED, 1998) the United Nations (UN) stated that education plays a central role in any sustainable development for our future. The idea of Education for Sustainable Development (ESD) was born. Since then, this concept has been under constant debate with respect to its objectives, terminology and implications (Sjöström, Rauch & Eilks, 2015). In order to thoroughly implement ESD in formal education, the UN formally announced the Decade of Education for Sustainable Development (DESD) for the years 2005-2014 (UNESCO, 2005a). DESD was inspired by two UN World Summits, which took place in Rio de Janeiro in 1992 and Johannesburg in 2002. Both summits

Correspondence to: Ingo Eilks
University of Bremen, Department of Biology and Chemistry, Leobener Str. NW2 28334 Bremen, Germany
Email: ingo.eilks@uni-bremen.de
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State of the literature

- Education for Sustainable Development (ESD) has been accepted as a worldwide goal in educational policy. ESD is a skills-oriented paradigm in education which meets the requirements of central educational theories like Activity Theory and Allgemeinbildung.
- Science and technology represent central aspects of any sustainable development, making science and technology education especially responsible for integrating ESD into teaching and learning.
- Implementation of ESD in science education is still insufficiently developed.

Contribution of this paper to the literature

- This paper reviews central ESD educational justifications and frameworks from the viewpoint of science education.
- It suggests some basic strategies for connecting ESD and science education and reflects upon their various potentials using selected examples.
- It gives an overview of 15 years of research and development by the chemistry education group at the University of Bremen, which has worked at integrating ESD into science teaching and science teacher education.

concluded that education should be one of the keys for achieving sustainable development. Proper education was suggested for making future generations better able to understand the integrated nature of the economic, ecological and societal changes involved. It would teach them how to actively participate in shaping society for a sustainable future (UNESCO, 2005a; McKeown, 2006; De Haan, Bormann & Leicht, 2010).

Use of sustainable development as a regulatory idea implies inherent contradictions, dilemmas and conflicting goals (Rauch, 2004). This represents a great challenge, but also shows considerable potential for enhancing innovative curricula and pedagogies in education. The vision of ESD includes a community of learners (teachers, pupils, students, researchers), which identifies with both topic interrelatedness and various options for action and intervention. Simultaneously, each individual in such a community needs to reflect upon his/her personal actions before coming to a decision in a joint forum.

This paper gives insights into roughly 15 years of ESD research in connection with societally oriented science education performed at the Institute of Science Education (IDN) at the University of Bremen (see also e.g. Marks, Stuckey, Belova & Eilks, 2014). It suggests different strategies for implementing ESD in science teaching, which are illustrated by various cases researching lower and upper secondary science education. The examples show that a thorough combination of the ESD philosophical framework with the science teaching based on socio-scientific issues-based education has great potential for developing many general educational skills both in and beyond the science classroom. However, this paper also addresses several lacking elements of and necessary developments for ESD in the future.

BACKGROUND

In central Europe, the idea of sustainability mainly emerged in the discipline of forestry in the 18th century (Burmeister, Rauch & Eilks, 2012). Sustainable use of forest resources came to be defined as cutting no more trees in a forest than you could replace with younger trees maturing in the same amount of time. From the beginning, this concept was viewed as an avenue for providing both ecological and economic stability. However, about a century later in the 1970s it was at first the aspect of ecological sustainability which eventually found its way into a broad public discussion.

After the Brundtland Report was released by the UN in 1987, the concept of sustainable development became increasingly more precise. Contributions focusing on sustainable development came from all academic domains. Today, the most common model of sustainable development consists of three domains, which attempt to ensure sustainability in the areas of ecology, economics and society (UN, 2005). Other competitive models have also been suggested, e.g. models including additional dimensions like cultural and institutional sustainability (see Hawkes, 2001). One good example of enhancing the focus of sustainability models is the ongoing debate over the role of culture as a dimension. The destruction of rain forests illustrates this point. Cutting forests to create land for agricultural products or for the production of biofuels necessarily touches upon several important questions. These include the loss of potentially unique ecosystems, endangerment of biodiversity levels, difficulties in calculating real economic benefits, and serious reflections on the working conditions experienced by the farm workers. Despite these important considerations, another baseline problem with rain forest destruction remains. Indigenous peoples are faced with the eventuality of losing not just their livelihoods, but also their cultures and languages, too. Be this as it may, the most common model of sustainable development today remains the three-pillar model described above, which encompasses ecological, economic and social sustainability (Figure 1).

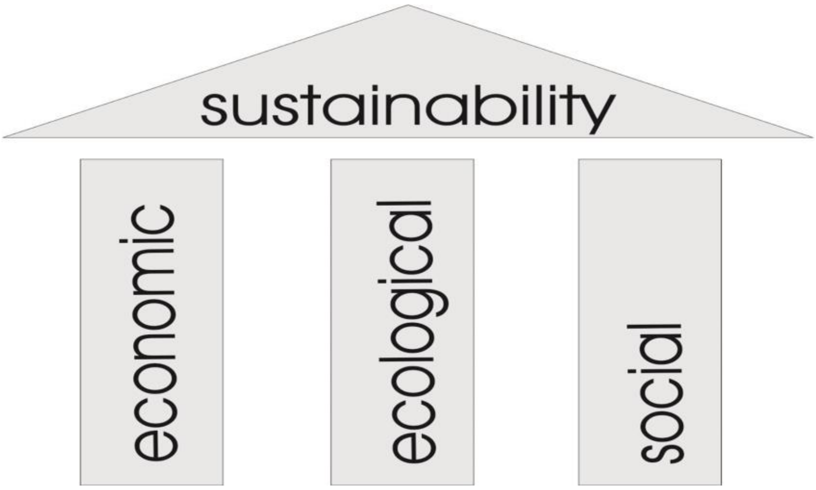

Figure 1. The three pillars model of sustainability

The three-pillar model of sustainability has been widely accepted, but has also received criticism as to whether or not it represents a satisfactory foundation for dealing with educational issues concerning sustainability. Wheeler (2000) outlined several such criticisms, stressing the fact that being forced to simultaneously think in three interactive, yet quite independent domains makes it even more difficult to learn the proper way to act. Wheeler instead suggested using five interacting perspectives of sustainable development for which ESD should be held accountable:

- thinking about and affecting the future
- designing sustainable communities
- proper stewardship of natural resources
- using sustainable economics
- globalization

Since different models of sustainable development exist, we are also faced with various ESD models. Wheeler's model is only one among many, however, most of the models contain some essentials in common. For example, Burmeister et al. (2012) derived the essential elements of most ESD models with respect to the works of Paden (2000), McKeown (2002; 2006), UNESCO (2005b) and De Haan (2006). These can be identified as:

- Learning about natural and man-made environments using an integrated view of their social, political, ecological and economical (and possibly cultural) dimensions, including involvement at the local and global levels.
- Focusing on participatory learning while promoting citizenship skills through an ethics- and values-driven approach.
- Orienting learning around system-based thinking, including the use of interdisciplinary, learner-centered, experiential, and inquiry-based methods.
- Focusing on life-long learning as a perspective which integrates formal, non-fromal and informal education.

Most ESD models suggest a thorough orientation around societal issues, an interdisciplinary approach, and a change in pedagogy which far outstrips any simple rearranging or altering of current curricula. Interdisciplinarity in this sense means merging different perspectives towards a societally relevant question. It also entails an incorporation of chemistry, biology and physics, including a combination of these subjects with perspectives taken from economics, the social sciences and the humanities. ESD approaches also demand implementation of a skills-oriented teaching paradigm in the sense of an education for sustainable development, which reaches far beyond education simply about sustainable development (McKeown, 2006). In his conclusion, Wheeler (2000) expressed hope that students will develop such skills to personally act on both the individual and community level. This includes developing:

A deep understanding of complex environmental, economic, and social systems,
Recognition of the importance of interconnectedness between these systems in a sustainable world, and
Respect for the diversity of 'points-of-view' and interpretations of complex issues stemming from cultural, racial, religious, ethnic, regional, and intergenerational perspectives. (p. 5)

Acknowledging the importance of education for sustainable development, the UN General Assembly enacted guidelines for implementing the DESD (UNESCO, 2006). Strategic fields of action were defined which address such factors as gender equality, the promotion of health issues, protection of the environment, rural development, promotion of peace and human security, supporting sustainable consumption, protection of cultural diversity, and bringing about sustainable urban development. In the foreground, these topics should not just be dealt with in the context of formal education. They should also be justifiable with respect to the following standards:

- Contention with societally relevant ESD topics demands collective thinking about their economic, ecological, social, and political dimensions.
- Any discussions and decision-making processes must be democratic in the sense that they inherently contain participatory elements.
- The final positions taken must be in accord with human rights protections, while not forgetting the background of global development.
- Dealing with specific situations and the final decisions made must leave open the possibility of questioning any particular point-of-view from multiple perspectives.
- Any final results must offer ideas for how the results themselves contribute to higher levels of quality with respect to the ability to act in the sense of the first four items listed here. (Heinrich, Minsch, Rauch, Schmidt & Vielhaber, 2007)

ESD provides direction for educational research, classroom teaching at all levels, and improving teacher education (UNESCO, 2005b, 2005c) with respect to education in general and science education in particular. It has became one of the central curriculum orientations defining science education (Eilks, Rauch, Ralle & Hofstein, 2013). It also demands more societally oriented science education (Hofstein, Eilks & Bybee, 2011; Holbrook & Rannikmäe, 2007). This represents a great challenge, but also shows considerable potential for enhancing innovative developments in education if performed in connection with ESD (Sjöström et al., 2015). With reference to UNESCO (2006), ESD for science education should therefore:

- Be interdisciplinary and holistic: ESD should be embedded in the entire science and technology curriculum and not merely be presented as a separate topic.
- Become value-driven: The ethical values and principles underpinning sustainable development should be accepted as the guiding principle of science and technology education, too.
- Promote critical thinking and problem solving: Addressing and understanding the dilemmas and challenges of sustainable development requires skills in critical thinking and problem solving.
- Be based on multi-dimensional methods: Art, drama, debate, experience, etc. should be used to construct a multi-faceted pedagogy which can cope with the multi-dimensional character of ESD.
- Involve participatory decision-making: Learners should be given the chance to participate in decisions and learn how they are to be made.
- Focus on applicability: Learning should be integrated into day-to-day personal and professional contexts.
- Achieve local relevance: Teaching should address global as well as local issues, including use of the language(s) which the learners most commonly use.

THE STATE OF IMPLEMENTATION

Anderson and Helms (2001) and Hattie (2009) have suggested that teachers remain the most important factor for educational reform. What teachers think, believe and know affects their teaching. These factors are therefore important when it comes to effectively and successfully reforming teaching practices. Any educational reform and implementation can only be successful if teachers` beliefs, their a priori knowledge and their attitudes are seriously taken into account when implementing reforms (Haney, Czerniak & Lumpe, 1996; Nespor, 1987). Unfortunately, formal insights into the area of teacher knowledge, beliefs and applied pedagogies concerning ESD are rare, particularly in the context of German chemistry education.

To create a reliable base for classroom innovation and reform in teacher education, two fundamental studies have already been performed by the chemistry education group at the University of Bremen, Germany. The studies were focusing pre-service chemistry student teachers and teacher trainees (Burmeister & Eilks, 2013a) and experienced in-service chemistry teachers in Germany (Burmeister, Schmidt-Jacob & Eilks, 2013). Both studies focused on the participants' a priori knowledge about sustainability and ESD, their ideas for implementing ESD in the classroom, and their personal attitudes towards ESD. These studies aimed at both educational innovation and addressing teachers' skills and knowledge base. In the first study questionnaires were used to examine a group of roughly 100 pre-service chemistry student teachers and the same amount of teacher trainees. The second case study employed semi-structured interviews, which were performed with the help of 16 experienced chemistry teachers.

Both studies revealed a remarkably coherent picture. The participants showed a persistent lack of theory-based knowledge concerning sustainability (e.g. the three-pillar model and the definitions in the Brundtland report). Knowledge about domain-specific concepts such as Green Chemistry was also rare, regardless of whether the participants were student teachers, teacher trainees, or experienced teachers. Their understanding of sustainability was often limited and stemmed primarily from the mass media, rather than from their teacher education programs. An ecological understanding was always in the foreground; connections to economic and social sustainability remained largely neglected.

ESD was an unfamiliar term for most of the (future) teachers. They had never been introduced to the concepts and philosophy of ESD. Many positive associations were made with the term, but teacher education had neglected making the (future) teachers familiar with both a coherent framework and a set of suitable classroom strategies. However, attitudes towards integrating sustainability education in education and science education were very positive. Pre- and in-service teachers were open-minded and interested in learning about how to integrate ESD into their science classes. These findings have many parallels with related studies on teachers' knowledge about climate change education, e.g. in Germany (Feierabend, Jokmin & Eilks, 2010).

MODELS INTEGRATING ESD INTO SCIENCE EDUCATION PRACTICES AND ILLUSTRATIVE EXAMPLES

There is no doubt that the fields of science and technology, including the industries directly related to them, are in the economic heart of every highly-developed industrial society (Bradley, 2005; Ware, 2001). Industry provides the raw materials necessary for every other type of business. It also is the foundation for energy supply, modern agriculture, health, and any innovative technologies. Unfortunately, many industries around the world have not always been very careful in the past. Quite often, they neither concerned themselves with the preservation of natural resources, nor did they give much thought to protecting the environment. Accidents both large and small have significantly contributed to the negative public image of industrial undertakings, e.g. in the field of chemistry (Hartings & Fahy, 2011).

The core role of science and technology for sustainable development in modern societies suggests the central role of science education in ESD (Bradley, 2005). The primary role of industrial production grounded in science and technology lends science education a central relevance with respect to ESD. Examples of this include: 1) the current debate over climate change and the potential avenues of corresponding action (e.g. Feierabend & Eilks, 2010), 2) (side-)effects on our personal lives caused by the production and consumption of goods (e.g. Marks & Eilks, 2010), 3) the various alternatives for energy production and use (e.g. Feierabend & Eilks, 2011), 4) innovative products which may aid in preserving natural resources (e.g. Burmeister & Eilks, 2012), and 5) the interactions of the chemical industry with local and regional economies and societies (e.g. Hofstein & Kesner, 2006). The studies by Burmeister and Eilks (2013a) and Burmeister et al. (2013) show that teachers would be open to ESD education, provided that feasible training and corresponding teaching materials are made available to them.

Developments in science and technology are interwoven with ecological, economic and societal impacts. The decisions resulting from these issues are even more important. Thus, science education shows great potential for bettering the level of general educational skills among students in the sense of participatory learning (Eilks, 2002). This is because recent societal developments can be tied directly to science and technology, then be dealt with using a multidimensional approach. Controversial issues selected carefully from industrial and technological sources allow students a chance to experience firsthand how questions related to science and technology are handled by our society (Eilks, Nielsen & Hofstein, 2014). By mimicking the societal mechanisms of debate and decision-making, learners have the opportunity to develop their personal capabilities in these areas (Stolz, Marks, Witteck & Eilks, 2013). Additionally, this can aid in training pupils' skills in all of the aspects touched upon above and help science education to achieve a broad range of goals (Marks & Eilks, 2009; Sadler, 2009; 2011).

But what answers can science and technology education offer to respond to this challenge? Based on a broad analysis of the science education literature with an eye towards chemistry, Burmeister et al. (2012) have suggested four different basic models for integrating science education and ESD.

Model 1: Adopting Principles from Sustainable Practices in Science and Technology for Hands-on Science Education Laboratory Work

The first model applies principles from sustainable practices in science and technology to practical work in science classes, inspired by the philosophy of Green Chemistry and Green Engineering (Anastas & Warner, 1998; Bodner 2015). Student experiments can be shifted from the macro- to the micro-scale, dangerous substances can be replaced by less poisonous alternatives, and catalysts can be used to stimulate reactions. ESD's potential, at least with respect to learning about chemistry's contribution to sustainable development, can be expanded upon, if students can recognize, compare and reflect upon the altered strategies. Students can learn how research programs and industry attempt to minimize the use of resources, maximize the production effects, and simultaneously protect the environment.

An example of this kind of activity is the EU-funded project called SALiS – Student Active Learning in Science (Kapanadze & Eilks, 2014). SALiS aims at promoting secondary school science teaching by supporting student-active experimental learning in science classes in countries such as Georgia and Moldova. From 2010 onward, the SALiS consortium jointly developed teacher training modules, school teaching materials, and an implementation concept for SALiS, which specifically promote the use of small-scale, low-cost laboratory experiments. Although well-equipped, suitable laboratory facilities dedicated to science teacher education were available in all SALiS partner institutions in the EU, the same is not the case in Georgia and Moldova. This was why the project also invested in strengthening the educational infrastructure in the institutions found in these countries. For the first time ever, specific science teacher education laboratories were established and equipped in the recipient institutions. A central focus of modernizing these laboratories was investment in a sustainable structure. With this in mind, the concept was based on the use of low-cost science equipment in teacher training laboratories from the very start. This included such cost-saving measures as: 1) the use of small-scale experiments with lower levels of reagent consumption, 2) more cost-effective experiments which used modified Petri dishes instead of buying more expensive glassware, 3) practical experiments substituting inexpensive medical equipment for costly lab material, e.g. manufacturing a functioning Hoffmann apparatus out of two syringes, and 4) specifically choosing chemicals and materials readily and cheaply available in supermarkets or home improvement stores in order to create simple, cheap and safe student experiments on a minimal budget. This approach was chosen so that the laboratories could remain in operation long after the financial support of the EU had disappeared.

Model 2: Adding Sustainable Science as Content in the Science and Technology Curriculum

This model takes the strategies and efforts of science and technology to contribute to sustainability development into account when deciding which content to include in the science curriculum. In this approach, the basic technology principles behind sustainable science and its industrial applications appear as topics within the science curriculum. Practical examples of this include 1) the development of efficient industrial processes in the fields of energy and raw materials conservation, 2) research into the structure, properties and application of innovative products and technologies, and 3) consideration of the production methods behind products stemming from renewable resources.

Learning about science and technology research's contributions to sustainable development can also offer a basis to better understand various developments in wide-ranging fields. The strength of this approach is that it highlights the learning of the actual science disguised behind everyday processes and end products. This makes them more meaningful to students (Pilot & Bulte, 2006). There are many examples which use such contexts, e.g. establishing connections to industry and modern chemistry in secondary school (Hofstein & Kesner, 2006; Garner, Siol & Eilks, 2014) or at the primary level (Evans, Hogarth & Parvin, 2004). However, a thorough understanding of the interplay between science, technology and society (in ESD terms: the interplay of economic, ecological and societal sustainability) will not take place if learners' concentration is primarily focused on, or even restricted to, the learning of the content behind its technological application. In such a scenario, the general skills necessary for participating in societal debates on socio-scientific issues will hardly have a chance to emerge.

Model 3: Using Controversial Sustainability Questions for the Socio-scientific Issues Driven Science Education

The third model drives science learning using a critical context-based approach by integrating socio-scientific issues (SSI) into the curriculum. This has the advantage of adding the tension and relevance of current societal debates to the learning process (Stolz et al., 2013). SSI teaching in this case goes farther than many context-based curricula currently do (Marks & Eilks, 2009; Marks et al., 2014). SSI-based science education generally does not focus on the learning of science as a subject or on sustainability issues per se as primary goals (Sadler, 2011). Instead, lessons tend to mold sustainable development education by developing general educational skills in the area of an individual's actions as a responsible member of society. This model's approach varies from that of the second model in that it simultaneously includes both scientific knowledge and reflection upon societal debates on the practical, technical applications of such knowledge as factors to be learned. This third model focuses on learning exactly how developments in science and technology can be and actually are evaluated and discussed within society using all of the above-mentioned sustainability dimensions (e.g. Burmeister & Eilks, 2012). This approach not only constitutes the explicit learning of science and technology, but also includes learning about science and technology as it is dealt with in society.

Examples with respect to ESD from a chemistry point of view can include: 1) the ongoing controversy about the use of biofuels (e.g. Eilks, 2002; Feierabend & Eilks, 2011), 2) the application of specific compounds and their alternatives in everyday products (Marks & Eilks, 2010), or 3) the evaluation of innovative products from science and technology using a multidimensional approach (Burmeister & Eilks, 2012). The ability to understand societal debates and develop appropriate skills to actively participate in them is systematically built into the lesson plans. Students learn how to take part in societal decision-making processes in order to contribute to shaping a sustainable future. This is supported by the use e.g. of role-playing exercises (Eilks, 2002), discovering how science representation the media (Marks & Eilks, 2009), business games on how political decisions are tied to questions taken from science and technology (Feierabend & Eilks, 2011), or discussing which role science plays (or should play) in advertising (Belova & Eilks, 2014). The strength of this approach is that it is skills-oriented with a sharp focus on ESD. It closely mirrors the differentiation defined by Holbrook and Rannikmae (2007), who have demanded more education through science instead of mere science through education.

Model 4: Science Education as a Part of ESD-Driven School Development

The fourth model integrates science and technology education into ESD-driven development for an institution such as an entire primary or secondary school (Rauch, 2002). Such an approach demands an opening of the classroom environment (Breitung, Mayer & Mogensen, 2005; De Haan, 2006). School life becomes a part of ESD. All shareholders in the school system are required to explore future challenges, to clarify values, and to reflect on both learning and on actively taking part in society in the light of ESD. Science and technology education can help contribute to such an altered teaching culture. Many opportunities exist for opening science and technology teaching to reflect how this domain influences us in the here-and-now. This includes our current lives both inside and outside of schools or other educational institutions. Science education no longer needs to stop at the point where teaching is limited to describing the science and technology theories and knowledge behind sustainability issues and potential avenues of action. Science and technology lessons and school life morph into an action-based pattern of living and learning.

One example from our research and development makes use of non-formal learning as a catalyst for school innovation (Garner, Hayes & Eilks, 2014). In our non-formal school projects, modules are formed connecting formal school education with non-formal laboratory workshops at the university and visits to research laboratories and industrial settings (Garner, Huwer, Siol, Hempelmann & Eilks, 2015). Topics including modern strategies in science and technology research thereby become open for innovative labwork outside of school. They are also directly connected to authentic developments in research and development in the real world.

In teaching practice, all four of the above-mentioned models may overlap or even be combined in order to place a stronger focus on sustainability issues connected to science education. Of course, combining and contrasting the different approaches also depends on the question of whether they should be applied to primary, secondary, or higher science education. A debate is currently underway as to whether all four models belong to ESD teaching. McKeown (2006) suggests, for example, that pure learning about sustainable development does not constitute ESD education:

> *"An important distinction is the difference between education about sustainable development and education for sustainable development. The first is an awareness lesson or theoretical discussion. The second is the use of education as a tool to achieve sustainability. In our opinion, more than a theoretical discussion is needed at this critical juncture in time. While some people argue that 'for' indicates indoctrination, we think 'for' indicates a purpose. All education serves a purpose or society would not invest in it."*

All four models can serve as tools for learning either about or for sustainable development (Burmeister et al, 2012). Table 1 shows the ESD potential of each of the four models. It also presents their differing potential with respect to learning about sustainable development, learning for sustainable development, and directly contributing to sustainable development because of imminent changes in social, ecological or economic practices.

Table 1. The Potential of the Four Basic Models for Dealing with ESD in Chemistry Education (- = low; o = medium; + = high; ++ = very high)

Potential for …	Model 1	Model 2	Model 3	Model 4
… learning about sustainable development.	o	++	++	+
… learning for sustainable development.	-	-	++	++
… directly contributing to sustainable development.	o	-	-	+

We suggest that models 3 and 4 hold the most promise with respect to ESD as education for sustainable development (Burmeister et al., 2012). But we must also remain aware that ESD objectives make up only part of the overall goals of relevant science education (Stuckey, Hofstein, Mamlok-Naaman, Eilks, 2013). Understanding the nature of the subject and allowing students to orient themselves towards potential science and technology careers are also important objectives. These objectives might be better achieved through other curriculum strategies, i.e. using the approach taken by model 2. One also has to consider the fact that either a context-based or socio-scientific issues-based approach may offer easier implementation than Model 4 in established science curricula for purely practical reasons. For example, education about sustainable development as presented in Model 2 can be readily implemented into regular curricula with minimal curricular reorientation. Model 1 might actually provide the simplest path to take, since the strictest application of this model affects neither the curriculum nor the pedagogy involved in teaching. The only changes lie in the required chemicals, lab equipment and experimental procedures. However, Model 1 is also the most limited when it comes to contributing to overall ESD skill development.

CONCLUSION

ESD is a political goal and represents an educationally well-justified concept (Burmeister et al., 2012). It allows the inclusion of educational theories such as Activity Theory and Allgemeinbildung in the science classroom (Sjöström, 2013; Sjöström et al., 2015). ESD can contribute to all three dimensions of relevant science education: individual, societal and vocational relevance as outlined in Stuckey et al. (2013). Using ESD as the focus of a new educational paradigm containing innovative structures can promote educational reform beyond mere curriculum revision and domain-specific pedagogical innovation (Garner et al., 2014). However, implementation of ESD measures remains rare and in most cases focuses on content-driven approaches to teaching and learning, rather than context-based or SSI-based education or institutional development. In tertiary education, science teaching tends to limit the focus of sustainability-related issues to the scientific background and/or subject matter content, at least in certain domains and programs. We have seen that teachers' knowledge of ESD philosophy, pedagogy, potential resources, and classroom materials is limited, however, their attitudes towards implementing ESD remain generally positive (Burmeister & Eilks, 2013; Burmeister, Schmidt-Jacob & Eilks, 2013). This means that investments in curriculum development and teacher education are needed. A recent study by Burmeister and Eilks (2013b) on the development of an ESD teacher education module for pre-service chemistry teachers has shown that this approach can enrich science teacher training. However, the overall research foundation and curriculum development efforts remain fields were there is still much work to do with respect to schools, universities and teacher education. This is especially true when taking differing curriculum traditions and various cultural and socio-economic environments into account.

Author's Note

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