Relevant Chemistry Education for Sustainability❖

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Abstract

This chapter elaborates on three commonly suggested concepts used in the rhetoric for educational reform in science education. One suggestion is to raise the relevance of science education. Up until now, the word ‚relevance' in the science education literature has often been used with high degrees of uncertainty and ambiguity. Thus as the first concept, this paper presents a model for a comprehensive understanding of the meaning and dimensions of relevance in science education. Secondly, we will revisit the concept of the two visions of scientific literacy and suggest that there is a further, third vision needed for relevant chemistry education. A third input is the adoption of the philosophy of Education for Sustainable Development into science education. Some very recent ideas will also be presented for this area. The chapter elaborates on the connections of the three concepts when it comes to providing guidance for chemistry curriculum reform. Two illustrative cases from Germany and Israel will show how chemistry teaching can come up with the elaborated stages of all the three concepts to make chemistry learning relevant education for sustainability.

Introduction

'Relevance' belongs to the most oft-used key terms when it comes to reforms in science education. Teachers are asked to make their teaching 'more relevant' to avoid a loss in student interest and motivation. However, the term is often used with high degrees of uncertainty and ambiguity (Newton, 1988b). An analysis of the science education literature shows that there are various meanings when the term is used. The literature also shows different dimensions of relevance when it comes to science education: individual, societal and vocational relevance (Stuckey, Hofstein, Mamlok-Naaman & Eilks, 2013). The review by Stuckey et al. (2013), as well as the perspective paper by Hofstein, Eilks and Bybee (2011), suggest that the societal dimension is often the most neglected of the three. However, a stronger societal focus within science and chemistry education also can be justified by many different theories. Among these, are the concept of scientific literacy (Roberts, 2007) and the ideas of Education for Sustainable Development (ESD) (Burmeister, Rauch & Eilks, 2012). This paper will discuss all the three frameworks (relevance; scientific literacy; ESD) and try to identify whether and in which degree they overlap in guidance for chemistry education curriculum reform. This will be illustrated by two classroom examples from Germany and Israel.

Three suggested frameworks for educational reform in chemistry education

Understanding the meaning of relevance in science education

'Relevance' is a frequently used term when educational reforms are conducted. Teachers are supposed to provide students with 'more relevant' education in order to motivate them and make them curious about science (Holbrook, 2005). However, it is not always clear what is meant by making science education 'relevant'

and how to do it. Twenty-five years ago Newton (1988a) wrote:

The notion of relevance is not a simple one. It seems at the least unhelpful and at the worst counterproductive to urge a teacher to be relevant in terms which are abstract and diffuse. It might be useful if some aspects of the notion of relevance were to be clarified. (Newton, 1988a, p. 8)

A recent analysis of the literature showed that the term 'relevance' is still used in widely differing contexts and incorporates many different meanings and concepts (Stuckey et al., 2013). For example, relevance is used in the sense of taking interest in something (Holbrook, 2008), as a perception of meaningfulness (Westbroek, Klaassen, Bulte & Pilot, 2003), or as having positive consequences for promoting learner motivation (Keller, 1987). The term is connected to individual interest, but also includes future careers (European Commission, 2004) and real-life impacts on individuals and society (Stolz, Witteck, Marks & Eilks, 2013), e.g. in terms of growing prosperity and sustainable development (Knamiller, 1984). Only sometimes, relevance is explicitly stated to be multidimensional (Rannikmäe, Teppo & Holbrook, 2010; Stuckey et al., 2013).

One of the key questions regarding relevance is what exactly is considered to be relevant, to whom, at what time, and/or who decides. By looking for answers to the question: 'Who decides what is relevant?', Aikenhead (2003; 2006) gave seven different heuristic categories of experts (that might overlap to varying degrees), which include academic scientists, curriculum policy makers and researchers, science-based industry stakeholders, mass media and Internet representatives, economics and health experts, players in the area of cultural aspects, and students.

Because the term relevance has different meanings and because various contributors make widely differing suggestions as to what constitutes relevant science education, the concept also has different facets and dimensions. Aspects of what relevant science education is (or isn't) can be obtained from definitions of the general aims and orientations of education, as well as from within science education itself. Many theories can be used to derive issues which should be considered relevant science education. Among them are general theories like 'Allgemeinbildung' or 'Activity theory' as well as more science education-specific concepts like Scientific Literacy for All (cf. Stuckey et al., 2013). For example, Holbrook (2005) suggested various important aspects which need to be taken into consideration in order to raise the relevance of science education. These include the personal lives of the students, the workplace of the future, and its relationship to and status within society. Similar dimensions also exist in many older documents from the 1980s onwards, which suggest organizational schemes for making science education more relevant (see Harms & Yager, 1981; Hofstein & Yager, 1982; Schollum & Osborne, 1985; Newton, 1988b).

Summing up all the literature covering almost 50 years, Stuckey et al. (2013) suggested a definition for the term relevance and a corresponding model of its dimensions. This definition is connected to the ideas of consequences and fulfilling personal needs:

- *Science learning becomes relevant education whenever learning will have (positive) consequences for the student's life.*
- *Positive consequences can include:*

Fulfilling actual needs related to a student's personal interest or educational demands (of which learners are aware),

as well as The anticipation of future needs (of which students are not necessarily aware).

- *Relevance in science education covers both intrinsic and extrinsic components. The intrinsic dimensions encompass student's interests and motives; the extrinsic dimension covers ethically justified expectations of one's personal environment and the by the society in which they operate and live.*

Relevance can be considered to consist of three different dimensions: individual, societal and vocational. For science teaching, this means that relevant education must contribute to pupils' intellectual skill development, promote learner competency for current and future societal participation and address learners' vocational awareness and understanding of career chances. Each of the three dimensions encompasses a spectrum of present and future aspects. (p. 19)

The analysis revealed three dimensions of the meaning of 'relevance' in science education:

- *The individual dimension: the relevance of science education for the individual encompasses matching the learners' curiosity and interests, providing students with necessary and useful skills for coping with their everyday lives today and in the future, and contributing to the development of intellectual skills.*
- *The societal dimension: the relevance of science education from the societal viewpoint focuses on preparation of pupils for self-determination and a responsibly led life in society by understanding the interdependence and interaction of science and society, developing skills for societal participation and competencies for contributing to society's sustainable development.*
- *The vocational dimension: the relevance of science education in the vocational dimension is composed of offering orientation for future professions and careers, preparation for further academic or vocational training and opening up formal career chances (e.g. by having sufficient coursework and achievements to enter into any given higher education programme of study). (Stuckey et al., 2013, p. 18)*

Figure 1 suggests an illustrative model encompassing the three dimensions of relevance in science education. Each dimension covers extrinsic and intrinsic components as well as a range from present to future for the relevance of learning science. The three dimensions of the model are not solitary or hierarchically arranged. The dimensions overlap and many aspects can contribute to more than one dimension with respect to how they are interpreted and executed. For example, career orientation can be part of vocational relevance, but it may also link to personal curiosity or respond to a demand for more scientists, which enables prosperity for the society's future.

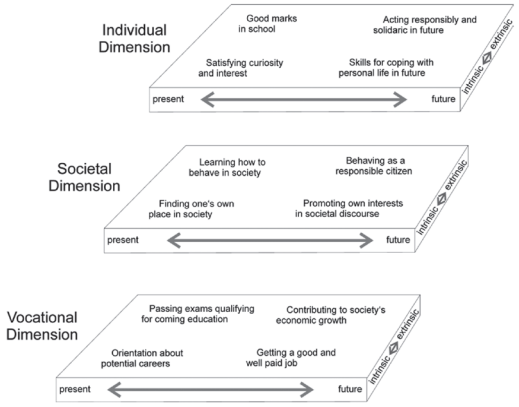

Figure 1. Model of relevance in science education (Stuckey et al., 2013)

The value of the model in Figure 1 was validated through focus group discussions with student teachers, trainee teachers, teachers, and science educators (Stuckey, Sperling, Mamlok-Naaman, Hofstein & Eilks, 2014). The participants suggested that this model can be a beneficial tool for reflecting upon curricula, textbooks, and teaching practices. The curricula and teaching examples which were evaluated as the most promising for promoting relevant science education were those that address all three dimensions at once. However, it is also important to maintain a good balance between them and keep them aligned with the lesson's target audience.

Based on reflections on different basic curriculum orientations in science education, this paper suggests that secondary science education is best served by socio-scientific, issues-based science curricula (Sadler, 2011), when attempting to cover all three dimensions in an integrated way. This potential can be further improved by opening the

pedagogy to societal practices and including references from the fields of industry and science-related professions.

A Vision III of scientific literacy

In 2007, Doug Roberts suggested two different visions of scientific literacy. In Vision I, the more traditional one, science learning in general and chemistry education in particular focuses first of all on learning content and concepts for later application. This approach was and is often organized along the inner structure of the academic discipline and mirrors traditional academic chemistry textbooks. For more meaningful education, Roberts suggested a more student-oriented vision, namely Vision II. He suggested that Vision II should focus on providing the learner understanding about the usefulness of scientific (chemistry) knowledge in life and society by starting science learning from meaningful contexts. Aikenhead (2006) connected the tension between the two approaches to different understandings of science education between 'pipeline science – preparing future scientists' and 'science for all'.

More recently, Sjöström and Eilks (2017) discussed that some scholars, inspired by the idea of education for more sustainability, have suggested that there should be a third vision, namely Vision III. Vision III is a humanistic and critical approach; it emphasizes science learning for scientific engagement (Liu, 2013; Yore, 2012) and 'knowing-in-action' (Aikenhead, 2007). Science education according to Vision III aims at strengthening the learning beyond the knowledge of chemistry content, contexts, and processes. It argues for general skill development via contention with issues of chemistry that are relevant for a sustainable development of our society and the global world. Sjöström, Eilks and Zuin (2016) discussed this approach with reference to the green chemistry movement. They ended up their discussion with sketching the philosophical foundation of what they call 'eco-reflexive science education'.

Figure 2 provides an organizer to understand the difference of Vision III from Visions I and II. It is developed based on Sjöström (2013), Sjöström and Talanquer (2014), and the visions I and II of scientific literacy by Roberts (2007). Where Visions I and II focus on content and contextualized knowledge and how it is applied in everyday life and Science-Technology-Society contexts, Vision III aims on critical skills development for actively shaping the future society in a sustainable fashion (Sjöström & Eilks 2017; Sjöström et al., 2016).

A Vision III based approach of chemistry education asks for educating critical and active citizens that take responsibility and act accordingly. Vision III asks for them in both communities, among the scientists and the non-scientists (Eilks et al., 2017). It is suggested that content knowledge of chemistry and contextual understanding about chemistry are necessary pre-requisites to participate informed in scientific and societal discourses on the technological applications of chemistry and its corresponding effects on the environment and society. However, it is also clear that this will not be enough. A critical stance is also needed that promotes understanding of the responsibility of any individual and in the same time directs the individual to act accordingly in society.

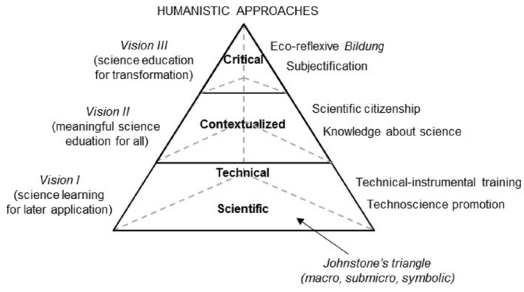

Figure 2. Three visions of scientific literacy (Sjöström & Eilks, 2016; Sjöström et al,, 2017).

Sjöström and Eilks (2017) suggest that for preparing the young generation to actively participate in societal discourse and decision making,

teaching about those socio-scientific issues (SSIs) is needed that are relevant for sustainable development of our society, today and in the future. Chemistry education needs to take into account multi perspectives on chemistry related issues including their ecological, economic, and societal impacts (Burmeister et al., 2012; Sjöström, 2013; Sjöström, Rauch & Eilks, 2015). Especially so called 'hot-type' SSIs are of potential to provoke a critical view towards development in science and technology (Simonneaux, 2014). Hot-type SSIs can be characterized by their authenticity and controversial perception in society (Stolz et al., 2013). Examples are alternative materials, renewable energy supply, nanotechnology, or use of new dyes, cosmetics, or pharmaceuticals. All of these can provide chances and benefits, but can also cause risks. Pedagogies are needed in chemistry education where students learn how to argue, how to use scientific evidences to inform the public, and how corresponding information can be obtained, and also how careful respective information needs to be evaluated and used (Sjöström et al., 2015). This is the case for school education for all learners, but it should be also the case for the next generation chemists educated in our universities (Eilks et al., 2016).

Education for sustainable development and science education

The emphasis of education for sustainable development (ESD) was suggested by the Agenda 21 at the United Nations Conference on Environment and Development (UNCED) conducted in Rio de Janeiro, Brazil, in 1992. More specifically, chapter 36 of Agenda 21 claims the following: *Education is critical for promoting sustainable development and improving the capacity of the people to address environment and development issues. While basic education provides the underpinning for any environmental and developmental education, the latter needs to be incorporated as an essential part of learning. Both formal and non-formal education is indispensable to changing people's attitudes so that they have the capacity to assess and address their sustainable development concerns. It is also critical for achieving environmental and ethical awareness, values and attitudes, skills and behavior consistent with sustainable development and for effective public participation in decision-making. To be effective, environment and development education should deal with the dynamics of both the physical/biological and socio-economic environment, and human (which may include spiritual) development should be integrated in all disciplines and should employ formal and non-formal methods and effective means of communication.*

The central focus of ESD is preparing the younger generation to become responsible citizens in the future. Students should be able to participate in a democratic society and to help in shaping future society in a sustainable fashion. They should learn to take responsibility for both themselves and future generations, based on the concept of sustainable development (de Haan, 2006).

There are different models of ESD. Nevertheless, most of these models contain some essentials in common. With respect to Paden (2000), McKeown (2002; 2006), UNESCO (2005), or De Haan (2006) the essential elements of most ESD models can be identified as:

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

All ESD models suggest a thorough orientation

on societal issues, an interdisciplinary approach and a change in pedagogy far outstripping a simple re-arranging or altering of curricula. In this context, interdisciplinary means bringing together the different perspectives towards a societally relevant question incorporating chemistry, biology and physics, but also includes combining these with aspects from the economy, the social sciences, and the humanities (i.e. ethics). ESD approaches also demand implementing a skills-oriented teaching paradigm in the above-mentioned sense of an education for sustainable development which goes beyond education about sustainable development (McKeown, 2006). In his conclusion, Wheeler (2000) expressed hope that students will develop skills and 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)*

Since science - especially chemistry and the industries related to it - are at the economic heart of every developed society (Bradley, 2005), science education is given a core role in ESD (Burmeister et al., 2012). In a recent review Burmeister et al. (2012) analyzed potential ways for integrating chemistry and science education into ESD. Four basic strategies were identified, here described in brief:

- Mode 1: Green chemistry principles are applied to laboratory practices used in teaching and learning of science.
- Mode 2: chemistry learning is contextualized by applications of sustainable science and technology practices.
- Mode 3: Socio-scientific issues become the driver for chemistry education, e.g. climate change, energy issues, risks and chances of products or processes, or environmental considerations.
- Mode 4: ESD becomes the driving force for school life's development, e.g. project work or networking schools with research and industry.

From the analysis provided by Burmeister et al. (2012), all four models can contribute to learning either about or for sustainable development. However, each of them would do so to a different degree and with variations in focus. Table 1 shows the estimated potential of each of the four basic modes for contributing to ESD. It also differentiates between learning about sustainable development, learning for sustainable development, and directly contributing to sustainable development, because of imminent changes in social, ecological or economic practices.

A balanced implementation and combination of the four modes might actually represent a promising strategy for achieving a broad range of ESD goals in science education. However, the four modes can also be considered as hierarchical distinctions, with the later modes including essential elements of the earlier ones. From this point of view, modes 3 and 4 seem to hold the most promise with respect to ESD as education *for* sustainable development (Burmeister et al., 2012). This would mean an SSI-based approach to science teaching with changes in the school culture, e.g. opening school life to societal areas like industry and science-related businesses. This would be the same conclusion as reached in the discussions of the relevance of science education and the Vision III for scientific literacy in the previous sections.

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

Table 1. Reflection on the potential of the four basic models for dealing with ESD in Chemistry education (- = low; o = medium; + = high; ++ = very high)

Two classroom examples from Germany and Israel

In this section we will present two evidence-based developed teaching and learning modules from chemistry education in Germany and Israel. Both examples combine a focus on all the three dimensions of relevant science education, they aim on general educational capabilities and skills for societal participation, and both examples can be understood as 'hot-type' socio-scientific issues as they are suggested following the three theoretical approaches discussed to be of the most potential to implement ESD for more relevant and skills oriented chemistry education for sustainability.

Bioplastics or conventional plastics – an example from Germany

Recently, Burmeister and Eilks (2012) presented a lesson plan for chemistry education in Germany structured around ESD philosophies. The lesson plan follows the socio-critical and problem-oriented curriculum model for science education as described by Marks and Eilks (2009). The lesson starts with a textual approach based on excerpts from authentic, controversial magazine reports and brochures covering the use of conventional plastics, comparing them with emerging environmental problems, and suggesting bioplastics as an alternative. The material provokes questions about the basic chemistry of polymer materials as well as implications of their use, and also leads into questioning the value of their use with an eye towards ecological, economic and societal implications.

Students respond to this challenge by first learning the basic chemistry concepts behind the various kinds of plastics. Afterwards, however, they will revisit how this knowledge helps them in understanding the societal debate about conventional plastics and bio-plastics. A simple concept of sustainability is introduced to start reflection on different plastics (and their uses) with respect to ecological, economic and societal implications. This leads into a new pedagogical method called the product testing method (cf. Burmeister & Eilks, 2014). In this method the students perform as employees in a professional product testing agency. They compare different kinds of plastics: polyvinylchloride (PVC), polyethylene terephthalate (PET), and thermoplastic starch (TPS). Each of these plastics has individual advantages and disadvantages. The use of PVC is widely disputed in society, mainly because of certain plasticizers which are used in its production and problems with environmentally friendly recycling and storage of PVC waste. On the other hand PVC is very stable, has fantastic physical properties and can be easily and quite cheaply produced. In contrast, PET is viewed quite neutrally in the public debate. Nevertheless, discussions exist because of the serious environmental and social problems associated with the recycling process. It should be noted that PET waste is often exported to Third World countries with very low social and environmental standards. TPS as a biodegradable polymer usually enjoys very positive reviews in the popular press. However, TPS remains so far, expensive and has extremely limited potential for widespread application. To conclude, all the plastics have advantages and disadvantages which must be taken into account when a holistic evaluation is undertaken.

Pupils learn about the various advantages and disadvantages of each sort of material. A worksheet familiarizes learners with the different perspectives such an evaluation can encompass (Figure 3). These range from the economic aspects of production to availability and consumer friendliness issues to ecological concerns about production processes and waste removal in the context of 'green chemistry'. It also asks them to weight the importance of the different dimensions. The students have to negotiate weighting factors between the different dimensions of a potential evaluation, namely physical properties, ecological, economic and social impacts. Then the students evaluate the pros and cons of their specific sort of plastic.

M2 Evaluation Sheet

Plastics	My weighting factor	weighting factor of the group	Weighting factor of the class	my assessment	assessment of the expert group	assessment of the mixed group		
Evaluation criteria								
Plastic						PVC	TPS	PET
Green Chemistry	%	%	%					
Production and use without dangers for humans and environment								
No problems for disposal or recycling								
Production primarily from renewable resources								
Low energy costs for production								
Consumer and social interests	%	%	%					
Production, use and reuse take place according to West European social standards								
Safe usage for humans and animals also in the case of improper use (burning, swallowing, etc.)								
Products available cheaply everywhere								
Economy and industry	%	%	%					
Industrial production possible without subsidies								
Good marketability								
Recycling possible								
Material characteristics	%	%	%					
Good durability and long lifespan								
Good material properties and a broad area of usage								
Decision			100%					
Decision from the entire class								

Evaluation key:
++ = very good (1) + = good (2) o = satisfactory (3)
Θ = barely sufficient (4) – = unsatisfactory (5)

Figure 3. Evaluation sheet for the product testing method

The processes of weighing pros and cons and evaluating them are reflected upon in the final phase. At the heart of this reflection stand questions about how such evaluations occur and how they are influenced by the individual decisions of the people conducting the test and/or writing the reports. This reflection focuses on the role of scientific information and its constant transformation and filtering in the process of evaluation, but also touches upon the reliability of information sources and the transformative process, which occurs whenever members of consumer testing agencies use, relate and weight information in the sense of filtered information as suggested by Eilks, Nielsen and Hofstein (2014).

The ESD-driven classroom example presented above has great potential for developing relevant science education. It allows student learning in the individual domain on how to deal with growing waste problems in the environment, including making personal consumer choices. In the societal dimension students learn that society has to make decisions about environmental protection and regulations on the use of different products. This includes responding critically to consumer reports in the media. In the vocational range students get an idea what professional product testers do and what contributions from science and technology are provided to their measures.

Several industry-based modules have been developed in Israel since the late 1990s.

Bromine from the Dead Sea - an example from Israel

These modules target students who choose to specialize in advanced-level chemistry studies. The lessons include the underlying chemistry topics and concepts related to the industrial processes, the related technological, societal, economic, and environmental issues, and their interrelationships. Figure 4 presents the cover pages of the corresponding units. Figure 5 shows an overview of the aspects involved in one of the examples called Bromine from the Dead Sea (Hofstein & Kesner, 2006).

Until 2003 teaching one of the case-studies was obligatory and accounted for roughly 20% of the total curriculum. This was an integral part of the final matriculation examination, a central national examination prescribed by the Israeli Ministry of Education. About 65,000 students (an average of 6,500 students every year), studied one of the test cases. This represented 100% of the students taking chemistry as a major during these years. Although the case-studies are not obligatory today, roughly 400 students every year study them as an elective module. The last unit, which was developed in 2007, focused on environmental issues such as water quality and global warming as the leading context for studying the relevant scientific concepts. The unit is an elective for chemistry majors. During 2008-2013 about 3500 students (about 500 students every year) studied the unit. This represents about 10% of all chemistry majors and the number is gradually growing.

In order to incorporate sustainability issues and competencies into the formal curriculum, the students are asked to address environmental dilemmas like producing bromine near the fragile Dead Sea ecosystem (Figure 5). They are also required to reflect upon the advantages and disadvantages of issues such as the location of an industrial plant, various industrial processes, different construction materials, and available

separation techniques. They are forced to think about the pros and cons of certain issues, to suggest solutions and to recommend a compromise solution based on scientific data. The rationale behind this pedagogy is that active participation leads to a better understanding of the issues at hand and also increases students' personal interest. Some of the activities are based on group work in order to encourage the students to conduct collaborative discussions, compare different solutions with their partners, and evaluate information.

Figure 4. Overview of the different case study materials

Development of several modules included guided activities in order to promote the meaningful inclusion of field trips during chemistry education. Excursions are known to be very important and motivating for students (Orion & Hofstein, 1994). However, this is true only if the field trip is set up properly, the necessary learning materials are provided and an appropriate pedagogical approach is employed. Orion and Hofstein suggested several guiding principles, which were adapted for this purpose:

- A pre-visit phase to equip the students with necessary background information,
- An educationally effective visit to maximize learning,
- A carefully planned and orchestrated actual visit to the industrial plant,
- And a post-visit (summary) phase in which a discussion regarding the students' experiences was conducted in the classroom.

Orion and Hofstein (1994) found that in test cases strictly following the suggested instructional model, students demonstrated significant improvements in their knowledge and attitudes as compared to students in classes with a less- or non-structured approach. To make this model adequate for field trips to industrial sites and natural areas where an environmental conflict is taking place, we prepared a set of manuals for such visits. Teachers underwent professional development training, including gaining scientific and technological background knowledge about an industrial plant or an environmental issue. They also learned methods to help prepare their students for such visits. About 3500 students participate in the structured field trips every year.

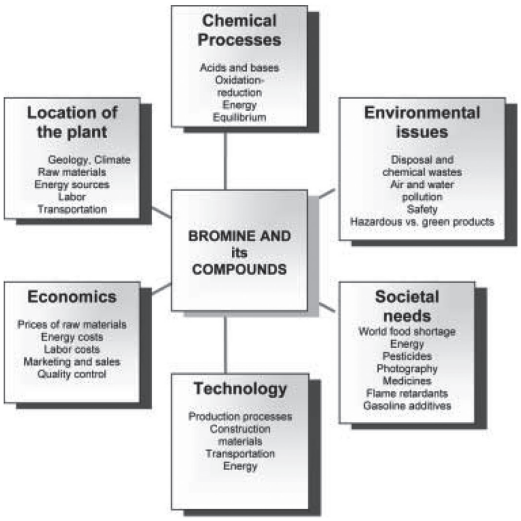

Figure 5. Overview of the case study on "Bromine and Its Compounds"

These ESD-driven classroom examples of industrial chemistry case studies have shown great potential for contributing to relevant science education. Students can learn in the individual domain how they should react to environmental challenges at the private and local levels, as well

as how they should behave as a consumer. In the societal dimension students learn how society makes decisions at the local and national level, how regulations and investments in industry come about, and how entrepreneurship and society interact. In the vocational range the students get an idea of which jobs are connected to the chemical industry and which chemistry-related businesses exist in the country.

Conclusions

Combining the ideas of relevant science education and ESD offers great opportunities for innovations in the chemistry curriculum towards Vision III scientific literacy. Especially SSI-based science education has strong potential for implementing ESD in chemistry teaching for more relevant science teaching and learning. The concepts discussed above for understanding the different dimensions of relevant science education, different visions of scientific literacy and the different modes of ESD-driven science education practices offer good tools for reflecting on science education curricula and teaching practices and also for guiding reform thereof.

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