INGO EILKS, FRANZ RAUCH, BERND RALLE & AVI HOFSTEIN

1. HOW TO ALLOCATE THE CHEMISTRY CURRICULUM BETWEEN SCIENCE AND SOCIETY

Chemistry curricula as a whole, or single lesson plans can use different approaches towards the learning of chemistry. Some are arranged parallel to academic chemistry; others provide meaningful contexts to motivate the learning of chemistry. Chemistry curriculum approaches can stem from the structure of the discipline, or history of chemistry, via everyday life contexts, industrial applications, or environmental issues, towards socio-scientific issues. This chapter suggests that every chemistry curriculum and even every single lesson plan uses one of these approaches. Each approach has a different justification, each one has different potential for promoting a certain set of objectives. One has to be aware, that by selecting one of the approaches the curriculum also gives the learner a certain emphasis towards chemistry. An overview about the different objectives and justifications is given to provide a range of possibilities for structuring chemistry curricula.

THEORETICAL BASIS

> *As a consequence of the ever-accelerating accumulation of scientific knowledge, curricula have become over-loaded with content. The consequences of high content loads have been that curricula are too often aggregations of isolated facts detached from their scientific origin.*
> (John Gilbert, 2006, p. 958)

Preparing future scientists vs. science education for all

When reviewing chemistry and science curricula from the 1960s and 1970s one can see that at that time the main goal of science curricula in general, and chemistry curricula in particular, was to give a limited portion of students a solid foundation in science to recruit and prepare these few students for future careers in science, engineering, or medicine. The results were that science curricula mainly focused on the learning of pure chemistry and were structured analogous to chemistry textbooks from the university. By the end of the day, chemistry was

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considered by a majority of students as being a subject for only a very few intrinsic motivated students (see Chapter 3) and less connected to their life and interests.

Since the 1980s, new goals and standards for science curricula emerged, i.e. the concept of *Scientific Literacy for all*. The focus was no longer the preparation of single students for their career in science and engineering. Most national science education standards worldwide started acknowledging that every future citizen needs a basic understanding of science in general and of chemistry in particular. This re-orientation of the objectives of science education led to intense debate about a potentially promising orientation and structure of the chemistry curriculum to fulfill the newly set goals. For a synopsis on this debate and the arguments for change, see e.g. Hofstein, Eilks and Bybee (2011).

The re-orientation of the curriculum became guiding educational policy in many countries. New standards started asking chemistry education to more thoroughly contribute to general educational objectives. The innovative work *Science for All Americans* (Rutherford & Ahlgren, 1989), and subsequent publications by the Project 2061, e.g., *Benchmarks for Science Literacy* (AAAS, 1993) and the *National Science Education Standards* (NRC, 1996) in the USA, directly influenced similar national standards and policies in other countries such as the UK (National Curriculum, 2004), or Germany (KMK, 2004). In parallel, the OECD in their framework for the Program for International Student Assessment (PISA) described the overriding target for any science education to allow all students achieving scientific literacy in the means of: "*The capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the change made to it through human activity*" (OECD, 2006, p. 3) (see Chapter 2).

This idea is supported by a whole set of educational justifications. One of them stems from the central European tradition of *Allgemeinbildung* as the central objective of any formal or informal education (e.g. Elmose & Roth, 2005). Within Allgemeinbildung, the word part "Allgemein" (which can be translated as 'all' or 'general') has two dimensions. The first means achieving *Bildung* for *all* persons. The second dimension aims at Bildung in *all* human capacities that we can recognize in our time and with respect to those general problems that concern us all in our society within our epoch. The more difficult term to explain is the idea of *Bildung*. The starting point of the discussion about Bildung normally refers back to early works of Wilhelm von Humboldt in the late 18^{th} century and thus encompasses a tradition of more than 200 years. Today, Allgemeinbildung is seen as the ability to recognize and follow one's own interests and to being able to participate within a democratic society as a responsible citizen.

A similar focus can be reached by applying *Activity Theory* to science education (Holbrook & Rannikmäe, 2007). Activity Theory deals with the relationship of knowledge and learning with their use for societal practices. This link can be described as

> interlinking of knowledge and social practice through establishing a need (relevant in the eyes of students), identifying the motives (wanting to solve

> scientific problems and make socio-scientific decisions) leading to activity constituted by actions (learning in school towards becoming a scientifically literate, responsible citizen). (Holbrook & Rannikmäe, 2007, p. 1353)

The focus of these educational theories influences much our contemporary understanding of the objectives of the chemistry curriculum. Modern curricula for chemistry education emphasize both the learning of scientific theories and knowledge, but also the science-related skills needed for recognising and understanding science in questions about everyday life, for future career choices, and for decisions which pupils currently have to make on personal and societal issues (see Chapter 2).

In order to theoretically operate within these different dimensions, justifying chemistry education, we need to examine what is meant by relevance. The word 'relevance' is currently present in many debates about why so many students do not like or do not learn chemistry quite well. They often perceive their chemistry lesson as being irrelevant to them. It has been demonstrated in the context of chemistry education that students attend more readily to their studies if the subject matter presented to them is perceived as useful and relevant, than if it appears remote (Johnstone, 1981). However, the term 'relevance' is not a clear cut theoretical construct. For example the *ROSE – Relevance of Science Education Study* (see Chapter 3) uses the word relevance as a synonym for students' interest but does not really differentiate between the two terms. However, relevance can have a broader meaning.

In an early approach towards understanding relevance with respect to education, Keller (1983) defined relevance as the students' perception of whether the content they are taught satisfies their personal needs, personal goals, or career aims. In this set of needs, one has to keep in mind that students' future needs, goals and career aims might not be conscious to them at the time they are having chemistry lessons. Therefore, the question of relevance is not an easy one. The question of relevance always is connected to further questions, e.g. relevant to whom, for what something should be considered being relevant, or who is deciding about that.

Since the 1980s there were different suggestions for organizers regarding the question of relevance in science education (e.g. Newton, 1988; Harms & Yager, 1981). Among these ideas there are different aspects of potential relevance that can found in several papers. These aspects can be summed up in three dimensions of potential relevance chemistry education can have of which all three having an actual component (connected to the students' interest today) and a future component (of which the student might not be aware today) (see also Chapter 2):

– *Relevance for the individual*: meeting students' curiosity and interest, giving them necessary and useful skills for coping in their everyday life today and in future, or contributing the students' intellectual skill development.
– *Relevance for a future profession*: offering orientation for future professions, preparation for further academic or vocational training, or opening formal career chances (e.g. by having sufficient courses and achievements for being allowed to study medicine).

- *Relevance for the society*: understanding the interdependence and interaction of science and society, developing skills for societal participation, or competencies in contributing society's development.

Clearly, relevance in this setting means something different than interest. Especially, some components of the professional dimension often are not perceived by many students as being relevant in the time they are young. It might even happen that this dimension will not become really relevant to them at any time if they opt for a completely different profession. In other words, relevance can be related both with intrinsically motivating issues (being connected to the students' curiosity or interest and maybe when becoming societal interested), but it also can be related with extrinsically justified learning goals (e.g. getting the right courses and marks to be later accepted by a specific university programme). The combination of these different dimensions of relevance in the context of chemistry education has many important consequences for structuring the chemistry curriculum, both concerning the chemistry content, as well as for the instructional techniques. One has to be aware that not only the explicit information is presented to the students. A curriculum or lesson plan may also provide subtle hidden ideas to the students, e.g. the purpose of learning chemistry, its potential use, or about the nature of chemistry.

The idea of the curriculum emphases

In the 1980s, Doug Roberts reviewed science curricula covering almost one hundred years from the educational system of northern America. He found that every curriculum has, aside the specific content, a set of hidden messages about science itself. This set of message he called the curriculum emphasis, described as

> … a coherent set of messages about science (rather than within science). Such messages constitute objectives which go beyond learning the facts, principles, laws and theories of the subject matter itself – objectives which provide answers to the student question: Why am I learning this? (Roberts, 1982, p. 245)

From his analysis of the curricula, Roberts derived seven different emphases (Table 1). Although Roberts stated that these different curriculum emphases are not sharply detached from each other, that they might change by time, and that they are often combined towards completely new meanings, they nevertheless allow the teacher to reflect about his own focus of teaching chemistry, his curriculum or textbook.

More recently, Van Berkel (2005) tried to update and reflect the idea of the curriculum emphases with respect to more recent curricula and with focus of the domain of chemistry education. Van Berkel refined the original seven emphases into three more general emphases, or one might say general aims in most chemistry curricula (Table 2). These three basic emphases were found by Van Berkel to represent most chemistry curricula of today.

Table 1. The curriculum emphases on science by Roberts (1982) and illustrations with the focus on chemistry

Curriculum Emphases	***Description***	***Illustration***
Everyday coping	Science is presented as a way to understand natural or technical objects and events of everyday importance and relevance.	Learning chemistry facilitates the understanding of the function e.g. of detergents, fuels, or fertilizers.
Structure of science	The curriculum focuses the understanding of how science functions as an intellectual enterprise, e.g. the interplay of evidence and theory, the adequacy of a scientific model, or the theory development in science.	Learning is about e.g. bonding theory as a distinction principle between different kinds of matter, the difference between inorganic, organic and physical chemistry, or the development of the theory of atomic structure and the periodic system of the elements.
Science, technology and decisions	Science and technology are distinguished, and the difference from value-laden considerations in personal and societal decision making about scientific issues in everyday life is dealt with.	Socio-scientific issues, e.g. the use of bio-fuels, are not only dealt with concerning their scientific and technological background, but also ethical and societal values of their use and consequences to society are reflected.
Scientific skill development	The curriculum aims on the competence in the use of processes that are basic skills to all science.	General methods of solving problems and applying specific strategies and techniques from chemistry are dealt with.
Correct explanations	The curriculum stresses the "products" from science as accepted tools to correctly interpret events in the world.	Chemistry is offering accepted theories, like heat absorption in gases, to explain the greenhouse effect.
Self as explainer	The curriculum focuses the character of science as a cultural institution and as one of man's capabilities.	Growth of scientific knowledge is explained as a function of human thinking in a specific era and within cultural and intellectual preoccup-ations, e.g. along the change in the different atomic models in the early 20^{th} century.
Solid foundation	The role of science learning is to facilitate future science instructions.	Secondary chemistry should be organized to best prepare the students for later studying chemistry courses in the university.

Table 2. Refined curriculum emphases by Van Berkel (2005). Adapted from Van Driel, Bulte and Verloop (2007)

Fundamental Chemistry (FC)	Fundamental Chemistry emphases the preferential learning of theoretical concepts and facts. Behind this curriculum stands the philosophy that concepts and facts need to be taught first, because it is believed that they later on will provide the best basis for understanding phenomena from the natural world and provide the best starting point for the students' further education.
Knowledge Development in Chemistry (KDC)	A central orientation on Knowledge Development in Chemistry is connected with the idea that students should learn that, how, and in which socio-historical context knowledge in chemistry is and was developed. The students should learn to see chemistry as a culturally determined system, in which knowledge is constantly developing.
Chemistry, Technology, and Society (CTS)	Chemistry, Technology and Society focuses explicitly on the relationship between science and technology and the role of science within societal issues. It is believed that the students should learn to communicate and make decisions about societal issues that are connected to aspects of chemistry and technology.

Basic orientations of the chemistry curriculum

While each of the curriculum emphases discussed above is a representation of a set of messages behind the chemistry curriculum, different curricula also can often be characterised by some kind of a general characteristic of their textual approaches, or the structuring principle behind. De Jong (2006) differentiated four different domains that can be utilized for offering textual approaches towards the learning of chemistry:

- *The personal domain*: Connecting chemistry with the student's personal life.
- *The professional practice domain*: Providing information and background for future employment.
- *The professional and technological domain*: Enhancing the students understanding of science and technological applications.
- *The social and society domain*: Preparing the student to become, in the future, responsible citizens.

In using De Jong's four foci, we can obtain a whole range of general orientations the curriculum can use for the learning of chemistry. These general orientations offer textual approaches to start the lessons from, but the orientations also can be used as guiding principles for structuring the whole curriculum:

- *Structure of the discipline orientation*: The inner structure of the academic scientific discipline (chemistry) is used for structuring the curriculum. The basic focus is the learning of scientific theories and facts and their relation to one another. The school chemistry curriculum looks like a light version of a university textbook in general chemistry. This orientation is near to the FC curriculum emphasis outlined above.

- *History of science (chemistry) orientation*: The history of science is used to learn scientific content as it emerged in the past, but also to allow learning about the nature of chemistry and its historical development in the means of the KDC curriculum emphasis. Lesson plans are often planned along episodes from the history of chemistry.
- *Everyday life orientation*: Questions from everyday life are used to get an entry into the learning of chemistry. The approach is chosen so that learning chemistry has a meaning for the student. The student should feel a need to know about chemistry to cope with his life. E.g., the use of household cleaners is taken as a context for approaching acid-base-chemistry. This orientation is not easily connected to Van Berkel's curriculum emphasis. In most cases it is directed to FC, but with a broader view it can include also CTS.
- *Environmental orientation*: Environmental issues are used to provoke the learning of science behind the issue, but also about questions of environmental protection. Examples can be lesson plans about clean drinking water, air pollution, or acidic rain. Here we can assume the same curriculum emphasis as for the everyday life orientation, although environmental issues more thoroughly ask for reflection in the CTS means.
- *Technology and industry orientation*: Developments from chemical technology and industry are dealt with in order to learn about chemistry and its application. The teaching in a broader view focuses about the interplay of science and technology within society. E.g. crude oil distillation or the industrial production of important metals are used as issues for chemistry lesson plans. Here the focus is clearly towards the CTS emphasis.
- *Socio-scientific issues orientation*: Socio-scientific issues form the starting point of chemistry learning, allowing the students to develop general educational skills to prepare them to become responsible citizens in future. Examples are the debate around climate change or effects in the use of bio-fuels for economy, ecology and society. This orientation is the most explicit CTS-type approach.

"Knowledge Development in Chemistry"-oriented science curricula

While in the 1960s to the 1980s chemistry curricula were overwhelmingly structured as a mirror of academic chemistry textbooks, in the last 30 years a lot of alternatives were proposed by science education research and promoted within curriculum development. One idea was to place more focus on Van Berkel's KDC emphasis (see above). This point of view was considered to be an addition towards curricula which were more or less exclusively structured on the pure transmission of scientific theories and facts as stable and approved knowledge, following on from Roberts' emphasis of correct explanations.

The basic goal of KDC-driven curricula (e.g. discussed in McComas, 2004, or Hodson, 2008) is to enhance students' learning in the areas underpinning the content and theories of science. The students are taught to learn about the nature of chemistry itself. Curricula focusing on the nature of chemistry are intended to promote learning about how scientific knowledge is generated. The students should learn that scientific evidence is not an unalterable truth. Every scientific theory is culturally embedded into the epoch where it was developed. Chemical theories and models change over time and chemical facts can be reinterpreted in the light of new evidence. The history of chemistry is full of examples where theories were considered to be true until a new observation or a new theory damned the theory to be replaced (Wandersee & Baudoin Griffard, 2002).

A very impressive example from the history of chemistry is the theory of the Phlogiston. In the 17th and 18th century, Stahl's theory of the Phlogiston was broadly accepted by the scientific community. The theory states that objects get lighter when they are burned, which is also a commonly held alternative conception by young learners (see Chapter 4). This theory was explained by some kind of matter, the Phlogiston, escaping from the wood or candle while burning. After having found out that there are some cases of matter getting heavier while burning, e.g. the reaction of iron wool to iron oxide, an additional hypothesis was constructed, stating that Phlogiston can have a negative mass. In the end, it was the discovery of oxygen by Lavoisier in the late 18th century that brought the Phlogiston theory to fall. This is a very good example where one can see that chemical theories can be re-interpreted or even replaced in light of new evidence. Discussing such examples can be a valuable way towards avoiding naïve understandings of science as a linear and simple process (Van Berkel, De Vos, Verdonk, & Pilot, 2000).

When looking into the traditional content of secondary school science, one might think, learning about the change of chemical theories is no longer important. Indeed most of the central concepts from within the secondary chemistry curriculum, e.g. atomic structure or bonding theory, have not changed significantly in school chemistry in the last 50 years but, they did in science. Even today knowledge and understanding about the tentativeness of scientific theories and the nature of scientific models is of value for the scientifically literate citizen. A good example is climate change. In recent years, the theory of climate change was controversial even within the scientific community. And although the phenomenon of climate change has now became accepted by the vast majority of scientists all over the world, the models of climate change for predicting the development in the next decades change in short cycles. For responsible citizens it is important to have an understanding about this process of knowledge development in science, in order to be able to understand arguments in the political debate. Exemplary areas of how to use the history of chemistry and how to learn about the nature of models are discussed in the practice section below.

From "Fundamental Chemistry" driven curricula to context-based learning

A lot of curriculum innovation projects took place in the last decades. Most of them were jointly driven by two research-based findings: (i) A lack of motivation among the majority of students, as well as (ii) a lack of success in students' acquisition of applicable knowledge. These two facts were reported in several national and international large scale assessments, e.g. the PISA studies. Both findings led to the recognition that the application of the theory of situated cognition towards the field of chemistry education has been overlooked (Gilbert, 2006; Pilot & Bulte, 2006).

The theory of situated cognition (Greeno, 1998) points out that sustainable learning and developing the ability to apply the learned chemistry theory only takes place, if the learning process is embedded into the learner's life, therefore it is better to start from a context that makes sense to the learner (Figure 1). Science learning should start from contexts that are connected to the life of the students, their prior experiences, their interests, and therefore it should have a meaning to them. But, contexts also have to be chosen in such a way that they relate to the application of the learned knowledge. For the majority of the students who will not embark in a career as a chemist such a context will not originate from academic chemistry. As such the everyday lives of students and the society which they live in have the potential to offer meaningful contexts to the students.

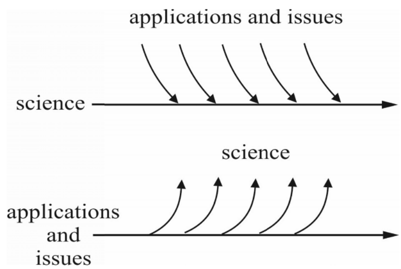

Figure 1. Traditional curricula driven by the structure of the discipline vs. curricula driven by applications and issues (Holman, 1987)

Since the 1980s projects were launched in many countries with the goal of teaching chemistry through a context-based approach. A common characteristic of theses approaches was described by Bennett and Lubben (2006) as:

- The use of everyday contexts and applications of science as the starting point for developing scientific (in our case chemistry) understanding,
- The adoption of student-centred approaches,
- Introducing and developing scientific ideas via a "spiral curriculum" (a curriculum where a scientific concept is dealt with repeatedly on different age levels leading to a more and more elaborated understanding), and
- Using a "need to know" approach.

When we use the word context today, it has many different educational meanings and connotations. In a reflection on context as an educational idea in chemistry education, Gilbert suggested as definition:

> A context must provide a coherent structural meaning for something new that is set within a broader perspective. These descriptions are consistent with the function of 'the use of contexts' in chemical education: students should be able to provide meaning to the learning of chemistry; they should experience their learning as relevant to some aspect of their lives and be able to construct coherent 'mental maps' of the subject. (Gilbert, 2006, p. 960)

In order to place a greater structure on context-based chemistry education, Gilbert (2006) considered a context to be a focal event and discussed four characteristics for any topic to become a context for chemistry education. Gilbert also discussed four general features of the use of contexts in chemistry education, to make clear what the vision of context-based chemistry education should look like (see also Table 3):

- *Context as a direct application of concepts*: An application is operated to illustrate a science concept's use and significance. Topics are chosen from the presumed personal/social everyday life of the students to which the concepts of chemistry are taught as abstractions. The concepts are then applied so that the students understand the applicability of the concept. This approach is strictly about how the concepts are used in the applications, almost as an afterthought, to the end of the theoretical treatment of concepts and often without a consideration of their cultural significance. As a post-hoc illustration, it is only an attempt to give meaning to a concept after it has been learnt and is therefore hardly meets the idea of situated learning.
- *Context as reciprocity between concepts and applications*: In this approach, applying contexts affects the meaning attributed to the concepts. Viewing concepts from different perspectives (the scientist, the engineer, the politician) implies different meanings for one concept. This model provides a better basis for context-based chemistry education than the first one, although there is no obvious need for students to value the setting as the social, spatial, or temporal framework for a community of practice. But the behavioral environment may be of higher quality, dependent on the teacher's understanding of the setting being used. The risk is that students do not see the relationship between a certain problem and why they should use some chemistry to deal with it, because the context of an expert does not automatically become a context of the learner.
- *Context provided as personal mental activity*: A specific person fixed in time and space who was seeking to explain a specific topic using chemistry is employed as context for learning chemistry. The model seems to be of greatest value when applied to cases of recent major events in chemistry. But, the use of this kind of events in chemistry will only be successful if students see the value of it. This is not always the case if the major events are historic, and as such took place long ago and have less meaning to the student. Also the chance for students to become actively involved is limited and the social dimension, through interaction within a community of practice, is missing.
- *Context as a social circumstance*: The social dimension of a context is put in focus as a cultural entity in society. This kind of context considers the importance of the context to the life of communities within society. Here, meaning-making can take place from two different perspectives, from a context as social surrounding or by a context as social activity. In science education, within this interpretation the context becomes intrinsic to student learning and fits most the ideas from situated learning and activity theory.

Table 3. Characteristics of context as a focal event by Gilbert (2006) with reference to Duranti and Goodwin (1992), an example, and implications for chemistry education

Characteristics	***Example: Chemistry of global warming***	***Consequences for context-based chemistry teaching***
A setting, a social, spatial, and temporal framework within which mental encounters with focal events are situated	Where, when, how is the focal event situated? The focal event is the general phenomenon of global warming, manifesting throughout the world in different ways.	The context must provide a setting of a social, spatial, and temporal framework for a community of practice. Particip-ation in it should allow the students productive interaction and develop personal identities from the perspective of that community. The community of practice must provide a framework for the setting of focal events. The settings must clearly arise from the everyday lives of the students, or social issues and industrial situations that are both of contemporary importance to society.
A behavioral en-vironment of the encounters, the way that the task(s), related to the focal event, have been ad-dressed, is used to frame the talk that then takes place	What do people do in this situation; what actions do they take? Various measures to reduce the production of relevant gases are discussed, as are measures to remove those already in the atmosphere.	The learning task must clearly bring a specifically designed behavioral environment into focus. The type of activity engaged in, is used to frame the talk that then takes place. The task form must include problems that are clear exemplifications of chemically important concepts.
The use of specific language, as the talk associated with the focal event that takes place	In what language do people speak about their actions? The molecular structures of relevant gases are discussed, with a particular empha-sis in a way that internal vibrations within the molecules lead to the observed effects.	Learners should be enabled to develop a coherent use of specific chemical language. Through the talk associated with the focal event, students should reach an understanding of the concepts involved. They should also come to acknowledge, that such specific language is a creation of human activity.
A relationship to extra-situational background knowledge	What is the background knowledge of those who act? The need for a general education about molecular structure and energy conversion is required.	Learners should perceive the relationship of any one focal event to relevant extra-situational, background knowledge. The students must be enabled to “resituate” specific language in order to address the focal event at hand. A vital source of focal events will be those with major public policy implications.

But, when trying to connect the chemistry curriculum along meaningful contexts, one has to be aware: Not every context considered by a teacher as being meaningful will necessarily work. A meaningful context for the teacher does not always signify that it is also meaningful to the student. Some examples of context-based science curricula from the US, the UK and Germany are discussed in the practice section below.

Curricula based on the "Chemistry, Technology, and Society" approach

A more thorough approach in context-based science education is subsumed under the term of Socio-Scientific Issues (SSI)-based science education. This view on the chemistry curriculum is strongly orientated towards the CTS curriculum emphasis. SSI approaches focus a specific orientation of potential contexts for science education, namely societal issues and concerns. The idea for promoting more learning about the interrelatedness of science, technology and society (STS) also started in the 1980s. Different acronyms were used and operated into whole curricula. Examples are Science-Technology-Society (STS) from Canada and the US (Solomon & Aikenhead, 1994), Science and Technology In Society (SATIS) from the UK (Holman, 1986), or Scientific and Technological Literacy for All (STL) in the framework of the UNESCO project 2000+ (Holbrook, 1998).

SSI oriented science education is more than solely being a specific form of context-based chemistry curricula. Coming from the interplay of science, technology and society in recent years i.e. Sadler and Zeidler (e.g. Sadler, 2004, 2011; Sadler & Zeidler, 2009) in the US, or Marks and Eilks (e.g. Eilks, 2002; Marks & Eilks, 2009) in Germany plead for more thoroughly thinking STS education beyond using STS contexts to promote the learning of science or chemistry. A step further is the thorough orientation on socio-scientific issues for better promoting general educational skills of participatory learning. Participatory learning means preparing students for participation in a democratic society.

According to Sadler (2004, p. 523), the most fruitful settings for this kind of chemistry teaching are those, "*which encourage personal connections between students and the issues discussed, explicitly address the value of justifying claims and expose the importance of attending to contradictory opinions*." For selecting respective issues with potential for participative learning Eilks, Nielsen and Hofstein (2012) suggested authenticity, relevance, being undetermined in a societal respect, potential for open discussion, and connection to a question of science and technology (Table 4). A more detailed discussion how to operate such an approach in the chemistry classroom is described in the practice section below.

Table 4. Criteria of selecting most powerful socio-scientific issues for chemistry learning and potential proofs by Eilks, Nielsen and Hofstein (2012)

Authenticity	The issue is authentic because it is – in fact – discussed in society.	It is checked for to whether the issue actually is discussed in everyday life media (newspapers, magazines, TV, advertisings, etc.)?
Relevance	The issue is relevant, because societal decisions on the issue will have direct impact on students' life, today or in future.	Scenarios are outlined and reflected upon regarding the impact specific societal decisions will have on how the individual could potentially act, e.g. as a consumer.
Evaluation undetermined in a socio-scientific respect	The societal evaluation is undetermined, it allows for different points of view.	The public debate is analysed to whether there are - in fact - different, controversial points of view outlined (by lobbyists, media, politicians, etc.)
Allows for open discussions	The issues can be openly discussed.	Thought experiments are conducted in order to consider whether expressing different points of view will harm the feelings of persons and groups because of their socio-economic background or religious and ethical concerns.
Deals with questions from science and technology	The issue centres around scientific and technological questions, for which the understanding of science and technology is fundamental.	The discourse in the media is analysed to examine whether basic concepts of science and technology are touched or used for argumentation – explicit or implicit.

Education for Sustainable Development (ESD) and the chemistry curriculum

As with human rights, sustainable development may be regarded as a regulatory idea for human life and society (Rauch, 2004). Such ideas do not indicate how an object is composed but serve as heuristic structures for reflection. They give direction to research and learning processes. In terms of sustainability this implies that the contradictions, dilemmas and conflicting targets inherent in this vision need to be constantly renegotiated in a process of discourse between participants in each concrete situation.

With a foundation built on the basis of understanding education in the tradition of *Allgemeinbildung*, the link between sustainable development and education can be described as follows: Sustainable development is an integral feature of the general mandate of education, the aim being to empower the succeeding generation to humanise their living conditions. The underlying notion of education is one that stresses self-development and self-determination of human beings who interact with the world, fellow humans, and themselves. Hence, education refers to the ability to contribute in a reflective and responsible manner to the development of society for a sustainable future. Therefore, learning should prepare students about how future may be shaped in a sustainable way (Burmeister, Rauch, & Eilks, 2012). This includes observation, analysis, and evaluation of concrete situations as creative and cooperative processes. Above all, learning aims are focused on acquiring a "*reflective ability to shape the world, rather than acting blind or adopting action patterns uncritically*" (Rauch, 2004).

In addition, the political arena has begun to place more emphasis on the global importance of sustainable development which has become influential for education. The UN announced a Decade of Education for Sustainable Development (DESD) for the years 2005-2014. The DESD was thought to play an important role in the global implementation of ESD. It suggests the promotion of understanding the interrelated nature of the economic, social and ecological aspects involved in society's development (Burmeister et al., 2012). The guidelines for implementing the UN Decade defined the following strategic fields of action: Equality between women and men, health promotion, environmental protection, rural development, peace and human security, sustainable consumption, cultural diversity, and sustainable urban development (UNESCO, 2006). The DESD also outlined standards for ESD type education:

– Issues dealt with in ESD should be reflected in the sense of sustainable development, encompassing a joint reflection on its economical, ecological, social and political sustainability.
– The contention must prove to be democratic in the sense that it inherently contains participative elements.
– The position must prove to be humane, for which it must at least be in accord with human rights protections – also against the background of global development.
– The position must open possibilities for questioning any standpoint from multiple perspectives, including the position holder's own perspective.
– The position must offer ideas as to how it contributes to facilitating a new quality in the ability to act within the sense of the items above.

For a more concrete application, a project in Switzerland developed a theoretical tool to be utilised for reflection when planning lessons with respect to ESD. "Spiders" are suggested to be used as an orientation for planning and reflecting upon lessons' potential for ESD (Kyburz-Graber, Nagel, & Odermatt, 2010). The developed "spiders" can help to reflect the potential of topics and methods to best support ESD. Each of the two "spiders" – one on the topics and one on the pedagogies – includes eight aspects (Figures 2 and 3).

Within the spider of topics (Figure 2), the segmentation refers to the triangle of sustainability: Two aspects are concerned with the environment, a further two with the economy and the final ones are related to society. By using the spider of topics when considering specific areas and lesson plans in chemistry education it can be evaluated at a glance to what degree the different aspects are incorporated in a teaching unit. Values are given to every aspect on a scale from 0 to 3. The greater the effect of an issue on a category, the higher the resulting value. In the end the filled out space within the lines will give an idea of the potential of an issue within chemistry education for ESD and how it balances the different sub-domains. The reader may apply the "spider" towards some of the teaching examples discussed in the practice section below.

In the "spider" of principles eight didactical principles serve as a guideline for education for sustainable development (Figure 3). The more the methods will allow the students to learn about the given objectives, the more potential a lesson plan will have to promote ESD.

Examples of ESD education in the framework of chemistry is given below in the practice section. For a more detailed discussion of ESD in chemistry education see Burmeister et al. (2012).

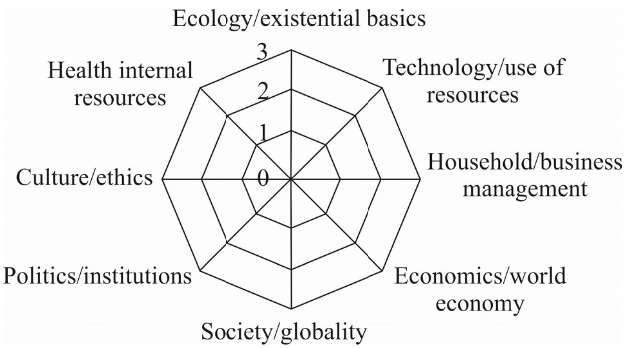

Figure 2. Spider of topics for reflecting ESD teaching (Kyburz-Graber et al., 2010)

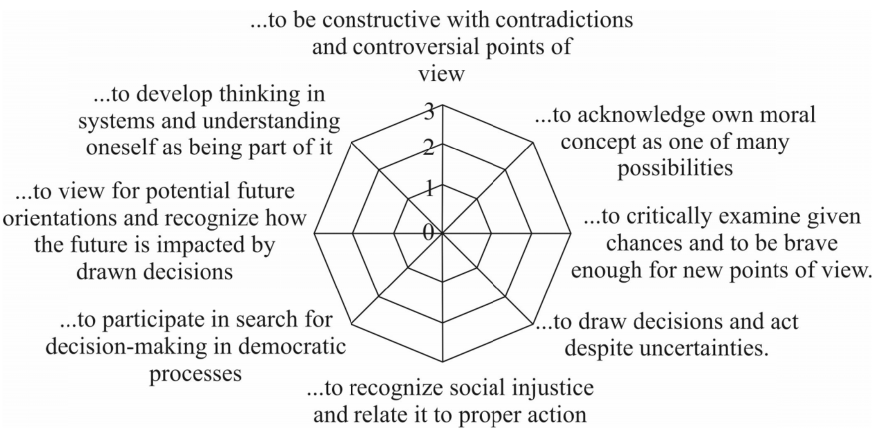

Figure 3. Spider of principles for reflecting ESD teaching (Kyburz-Graber et al., 2010)

Hindering factors in curriculum innovation and the model of different representations of a curriculum

Curriculum innovation is a complicated process. A new textbook, syllabus or teaching idea needs to be implemented. Research says that this process is not easy and needs bottom-up approaches considering teachers' pre-knowledge, beliefs and attitudes (Pilot & Bulte, 2006). With a focus on the reform towards more context-based chemistry education, Van Berkel (2005) stated that this is difficult for teachers who are experienced in traditionally structured curricula because they feel uncomfortable with the new situation. Thus, there is a latent trend to fall back on the conventional curriculum and its related pedagogy.

In addition, we have to be aware that the intended innovation not always is what comes to practice in class. Different perceptions by the teachers about the innovation will influence the process of curriculum change (Black & Atkin, 1996) as it does the expected assessment (Hart, 2002). To better understand the process of transformation while implementing a different curriculum the theory of Van den Akker (1998) regarding different representations of a curriculum may help. Van den Akker described six different representations which each operated curriculum has:

– The *ideal curriculum* describes the basic philosophy and rationale behind a curriculum, e.g. whether to use a context-based, SSI- or an ESD driven curriculum. This information is often laid down in general parts of a curriculum description and in the outline of its objectives.
– The *formal curriculum* describes the chosen examples, pedagogy and intended teacher and student activities, e.g. which experiments and materials to use or in which context and sequence to approach specific content. This is laid down e.g. in the textbook, worksheets, and teachers' guide.
– The *perceived curriculum* describes how its users (i.e. teachers) understand the curriculum. Their understanding is influenced by their prior-knowledge and beliefs. This means that implementing a curriculum needs an intense effort of good explanations and training to help teachers' understanding of the aims and pedagogies of the innovation while continuing to consider the teachers' prior-knowledge and beliefs. Essentially, every teacher will have a slightly different understanding of the written materials from the ideal and formal curriculum, based on their prior knowledge and beliefs.
– The *operational curriculum* is the actual instructional process taking place in the classroom. The actual processes are influenced by the teacher's understanding of the curriculum but also by factors influencing how it is conducted, e.g. statutory guidelines (not always congruent with a new curriculum), teacher-student-interaction, organisational restrictions, students' reaction on intended activities, or prospects on the assessment.
– The *experienced and attained curriculum* in the end mirrors the students learning outcomes. Even if the teacher would be able to transform the ideal and formal curriculum one to one into the operational curriculum every student will

perceive the instruction differently and their individual activities and learning processes will lead to different outcomes.

The theory of Van den Akker (1998) can be used as a tool for the teacher and for the curriculum developer. When comparing the ideal and formal curriculum with the operated and attained curriculum, teachers and curriculum innovators can reflect to whether the intended innovations were successful. Typically, the attained curriculum will not be fully congruent with the ideal curriculum. However, the model of the different representations of the curriculum can help to see where and how the ideal and the attained curriculum differ. If there are differences, understanding the transformation process described by the model of different representations of the curriculum, these different understandings may offer guidance to better effect curriculum implementation.

THE PRACTICE OF CHEMISTRY TEACHING

Structure of the discipline (SOD) approaches towards the chemistry curriculum

Traditional chemistry curricula, as they were developed in the 1960s and 1970s throughout the western world organise the curriculum starting from the structure of the discipline (SOD), in our case academic chemistry. A characterisation of this approach can be obtained from the AAAS guidelines for science curricula from 1962:

– Science education should present the learner with a real picture of science to include theories and models.
– Science education should present an authentic picture of a scientist and his/her method of research.
– Science education should present the nature of science (NOS).
– Science education should be structured and developed using the structure of the discipline approach.

Within the SOD approach, basic concepts and structures of the disciplines are chosen as the focal points of a curriculum. The idea of these curricula is to focus students' learning towards the basics of contemporary academic chemistry and to present the content in a logical (while scientific-theoretical) order. SOD curricula are often justified to give the students the best starting point for later academic studies in chemistry. The development of SOD programs was highly related to the goals and objectives for learning science in the time this tradition was founded, the 1960s and the early 1970s which was the recruitment of more scientists and engineers after the Sputnik-era in 1957. From the 1960s at least to the 1980s, the SOD approach was the key model of most of the chemistry curricula all over the world. This model is still predominant in several countries worldwide.

Units within SOD curricula are typically named like 'atomic structure,' 'acids and bases,' 'redox-reactions,' 'equilibrium' or 'chemical kinetics.' The sequence of units or the content list of the school textbook often looks like a condensed form of an academic textbook in chemistry. The lessons focus primarily on theory learning in the means of the FC curriculum emphasis. The lesson plans usually start from a phenomenon or problem of chemistry itself and follow in most cases an approach of first learning the theory and later – if at all – examining applications from industry or society for illustration.

Traditionally, SOD chemistry education is justified by the assumption that the fundamental concepts of chemistry, when understood correctly, enable students to conceptualise many of the phenomena from chemistry and similar phenomena that may be encountered elsewhere in related topics and subjects in the manner which Bruner suggested: "*Learning should not only take us somewhere; it should allow us later to go further more easily ... The more fundamental or basic is the idea, the greater will be its breadth of applicability to new problems*" (Bruner, 1962) But, Bruner also advocated that these fundamental ideas, once identified, should be constantly revisited and re-examined so that understanding deepens over time. In the end a spiral curriculum can be formed where a topic is re-visited on different levels (e.g. age levels) to get a deeper understanding in each of the circles of the spiral.

Today, we must say that SOD curricula in the foreground of the theories of scientific literacy and situated cognition must be reconsidered as being incongruous with modern educational theory. However, if there are homogenous groups of intrinsically motivated students (see Chapter 3), who have already decided upon a future career in a chemistry related domain; a SOD approach might be the most suitable. It is worth noting that not all SOD curricula look the same, as well as the content, the pedagogy behind them can also be very different. A look back into the history of the chemistry curricula may illustrate this, as well as how SOD curricula have innovated chemistry education in the past. This aspect should be examined through the lens of two innovation projects from the 1960s: *Nuffield Chemistry* from the UK and *CBA/CHEMStudy* from the US.

Nuffield Chemistry. The *Nuffield Chemistry* was developed in the UK in the 1960s (e.g. Atkin & Black, 2003). Prior to the Nuffield project, learning chemistry in the UK was characterised by the learning of a lot of independent facts. Textbooks looked like an encyclopaedia offering a lot of details. Learning chemistry by that time was mainly characterised by rote memorisation. Nuffield Chemistry aimed to shift chemistry teaching away from unconnected facts towards understanding the modern principles of chemistry, those principles that were regarded as being of fundamental importance. E.g., from just learning the names and properties of the elements, Nuffield chemistry aimed to develop an understanding of the systematic and trends within the Periodic Table of the Elements. Thus, learning chemistry was based firmly on three areas of students' understanding: (i) The Periodic Table of the Elements to provide a unifying pattern for the diverse properties of elements and their compounds, (ii) the relationship between sub-microscopic structure (atomic and molecular) and the properties of chemicals, and (iii) the way in which energy transfers can determine the feasibility and outcomes of reactions.

In order to foster a better understanding of the role of the fundamental principles, the Nuffield curriculum presented chemistry as an subject of systematic knowledge by (i) a breakdown of the barriers between the traditional division of inorganic, organic and physical chemistry, (ii) an integration of facts and concepts, (iii) integrating theory and practical work, and finally (iv) the connection of 'pure' and 'applied' chemistry through the inclusion of topics from special areas such as food science, biochemistry, chemical engineering or metallurgy.

Although by that time Nuffield Chemistry was highly innovative in its integrative view, with the focus on general principles in chemistry, and the integrated learning of theory and practical work, the main emphasis of the curriculum remained on fundamental pure chemistry. The integration with the applications of chemistry was part of the programme but played only a minor role. Later innovations from the Nuffield group became more and more open. In the end, teachers from the Nuffield project were leading contributors to the Salters Advanced Chemistry project in the 1980s, an approach towards context-based chemistry (see below).

CBA and CHEMStudy. Earlier in the USA, the *Chemical Bonds Approach (CBA)* and the *Chemical Education Material Study (CHEM Study)* were both developed in the early 1960s (e.g. De Boer, 1991; Merrill & Ridgway, 1969). The aims of both projects were parallel. In the case of CHEMStudy aims were stated to (i) diminish the current separation between scientists and teachers in the understanding of science, (ii) encourage teachers to undertake further study of chemistry courses that are geared to keep pace with advancing scientific frontiers, and thereby improve their teaching methods, (iii) stimulate and prepare those high school students whose purpose it is to continue the study of chemistry, and (iv) allow for those students, who will not continue the study of chemistry after high school, an understanding of the importance of science in current and future human activities.

The earlier approach of both was CBA focusing on the preparation of students for further chemistry studies. As Nuffield Chemistry did, CBA tried to take up the changed role of chemistry from its descriptive character of the past towards teaching the interplay of theory and experiment. CBA intended to acquaint the students with chemistry as a process of inquiry interrelating thinking and experimentation. The students were confronted with phenomena and experiments and had to explain them using general concepts like atomic structure, kinetic theory, and energy relations. The unifying concept behind CBA was the theory of chemical bonding. Although the outline of the project also emphasised the connection of chemistry with society and everyday living, there were only very few examples of that in the textbooks. CBA mainly focused on the presentation of the basic principles of chemistry, and the promotion of analytical, logical thinking skills in the field of science.

Later, CHEMStudy was developed as an addition to CBA, also focusing on those students with no further interest in chemistry studies beyond high school. CHEMStudy tried to reduce the volume of the syllabus by condensing the chemistry content to the most central principles. Also CHEMStudy, like in the

Nuffield example, tried to draw a concise picture of chemistry fitting to its basic theories, like atomic structure or bonding theory. The pedagogy of CHEMStudy was also based on integrating theory learning and laboratory work to give students a better idea of scientific inquiry. Unfortunately, these innovations suffered from lack of illustrations from everyday life and chemical industry, particularly when compared to the older textbooks in the US.

Thus CBA and CHEMStudy remained exclusively concerned with the learning of pure chemistry and frequently missed connecting chemistry learning to students' interests and needs.

SOD cuuricula today. Today we know the idea that if science is presented in a way in which it is known to scientists it will be inherently interesting to all the students represents a rather naïve assumption. The only focus of this approach always was and is the learning of pure content. In SOD curricula the conceptual approach (logical organisation of concept) becomes more important than the students' psychological (or motivational) development (Johnstone, 2006). Although there are some exceptions, most SOD programs do not include technological applications of chemistry, societal issues, or personal related ideas. Or if they do so, they are only used as some illustration at the end. The SOD approach in most of its applications from the 1960s until today neglects both, the theory of situated learning as well as the broad range of learners' varying attitudes, interests, and motivations (see Chapter 3). The approach only focuses on the interests of a small minority of students who will eventually embark into careers in science or engineering in their future.

Nevertheless, reflecting upon the structure of the discipline can offer the chemistry teacher a helpful opportunity to clarify the range and limitations of the most important theories of chemistry and their interrelatedness. But, using this as a global scheme for organising the chemistry curriculum SOD did not fulfill its promises from the past. Thus, modern chemistry curricula are moving thoroughly towards more integrated views, integrating the learning of concepts and theories starting from contexts and applications from everyday life and society. A figure from Reid (2000) provides an illustrative example about that change from structure of the discipline towards context-based chemistry education (Figure 4).

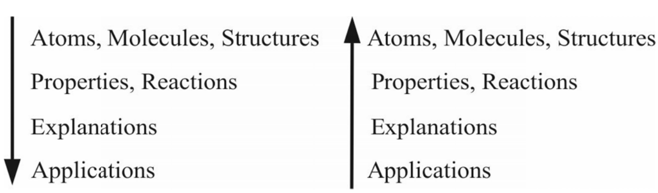

Figure 4. A change in directions (Reid, 2000)

Chemistry curricula base or focusing on the history of science (HOS)

Whereas SOD approaches often present chemical knowledge as static, chemistry curricula oriented on the history of science (HOS) try to make explicit that chemical facts and theories have a genesis. Two main justifications are given for using the HOS approach for structuring chemistry teaching. One justification is to use the HOS as a motivating story for challenging students thinking. Stories and anecdotes from the HOS can help students to better understand the concept itself. But, the HOS also can help students understanding how the concept was developed. Learning about the historical genesis of fundamental theories of chemistry can help students learning about the nature of chemistry in particular and the nature of science in general.

This point of view was also laid down in reform documents from the last 20 years. E.g. the Benchmarks for Science Literacy (AAAS, 1993) from the US state that "*there are two principal reasons for including some knowledge of history among the recommendations. One reason is that generalizations about how the scientific enterprise operates would be empty without concrete examples …. A second reason is that some episodes in the history of the scientific endeavor are of surpassing significance to our cultural heritage*." The National Science Education Standards (NRC, 1996) also from the US state that: "*in learning science, students need to understand that science reflects its history and is an ongoing, changing enterprise*."

Therefore, the main goals for teaching HOS as part of the chemistry curriculum is to present to the students with the idea that science is a human endeavor and that science is an ever developing entity. Students should understand that throughout history theories changed based on the inquiry and research conducted by human beings (scientists). In addition, students should be aware of the fact that many theories that prevail now may change in the future based on new research methods and new scientific theories.

One example that is often used in chemistry classrooms may illustrate this. In the core of learning about the nature of science is learning about scientific models. Among other characteristics it is important to understand that models in science are developed by scientists, these models are never fully true or false, and can be changed or replaced in the light of new evidence. Different historical models of atomic structure are a good example to reflect about the nature of models in chemistry education. Models of Democritus, Dalton, Thomson, Rutherford and Bohr can be compared in the chemistry classroom, e.g. in a drama play (see Chapter 7). Students can start reflecting about the predictive potential and limitations of the different models. But students can also learn about the time in which the models were developed and about the scientists behind them. Other examples are different models of oxidation and reduction or acid-base chemistry.

But, one has to be aware that it is always made clear to the students which of the concepts are still in use today and which only have value in the history of chemistry. If the students are not always aware of the clear distinction between the different models and the purpose of comparing them they can tend to mix the central ideas of the different models. They form ‘hybrid-models’ which can hinder a clear understanding of today’s most accepted explanation (Justi & Gilbert, 2002; Eilks, 2012). That means if the students are not sufficiently motivated, not taught clearly enough and if time is too short for comprehension a contention with different models can hinder learning far more than it will help the students to better sharpen their understanding. However, if applied with sufficient care, many studies assessed the value of educational effectiveness of including history in the curricula. Some studies show that the history of science can help students and teachers with conceptual change; it has potential to encourage positive attitudes towards science, promotes understanding of the nature of science, and is of potential to aid more sustainable learning.

Context-based chemistry curricula

Since the 1980s, a shift away from SOD and HOS curricula in many countries can be observed. This movement is still in operation. New curricula are available although in practice in many countries especially SOD curricula are still predominant. The reasons for change is a growing awareness about the problems in traditional chemistry teaching as they are discussed above. One big part of this movement for curriculum change in chemistry education is context-based (CB) chemistry education. For understanding this current change, three examples shall be discussed in brief. *ChemCom* from the USA, *Salters Advanced Chemistry* from the UK, and *Chemie im Kontext* from Germany.

ChemCom. One of the pioneering CB chemistry programs was *Chemistry in the community* (*ChemCom*) developed in the US in the 1980s (e.g. Schwartz, 2006). The curriculum aims at presenting chemistry along societal contexts on a “need to know” basis. Such contexts include e.g. air and water quality, the use of mineral resources, the production of various sources of energy, industrial chemistry, or chemistry of food and nutrition. ChemCom does not explicitly aim to train future chemists or those who will embark in any kind of science or technology studies. ChemCom’s intentions were chemistry education for all with a focus on preparing informed future citizens. Therefore, ChemCom is mainly driven by its society-related contexts and is less explicit, focusing on problem solving, learning chemistry by inquiry, or understanding the sub-microscopic nature of chemistry. An overview of how such a CB curriculum is presented is provided along with the overview of chapters from ChemCom in Table 5.

An additional feature of ChemCom is to give the students numerous decision making exercises of various complexity to allow them practice applying chemical knowledge in the context of addressing societal issues. Nevertheless, ChemCom is not a socio-scientific issues driven curriculum (see below), but covers a lot of elements in the same direction.

Table 5. Contexts used in ChemCom

The air we breathe	The fires of nuclear fission
Protecting the ozone layer	Energy from electron transfer
The chemistry of global warming	The world of plastics and polymers
Energy, chemistry, and society	Manipulating molecules and designing drugs
The water we drink	
Neutralizing the threat of acid rain	Nutrition: food for thought

Within ChemCom every unit followed the same pattern:

- Introduce students to a societal theme involving chemistry,
- Lead students to realise that they need to understand chemistry in order to evaluate ways of addressing the issue in an informed way, and
- Learning the relevant chemistry, showing its connection to the issue and using chemistry knowledge in decision making activities related to the scientific/ technological aspects of the issue.

The report regarding the effectiveness of the programme, related to the students and teachers, provided mixed findings. Regarding the teachers, Ware and Tinnesand (2005) reported that most teachers that were familiar with the course had strong feelings about it, some were very enthusiastic and others doubted the effectiveness of the approach. However, five editions were published up until 2005 and more than 2 million students from different backgrounds and with differing characteristics and school-types were involved in the programme. This might serve as an indication for the success of the course implementation.

Salters Advanced Chemistry. Also in the UK, a context-based course was developed at the University of York from the 1980s (e.g. Benett & Lubben, 2006). There were two main characteristics of the *Salters Chemistry* beyond ChemCom. One feature was the intensive involvement of chemistry teachers into the development, who provided many good ideas related to the pedagogical aspects of the course. This bottom-up approach proved to have the potential to enhance teachers' ownership related to the programme, a fact that had positive influence on the effectiveness of the implementation of the course in schools. The other initiative was a thorough focus on student-centred methods to enhance students' interest and motivation to learn chemistry.

In Salters Chemistry the chemistry concepts are outlined to fulfil the whole range of a typical chemistry syllabus. But the outline is not used as the structure for the curriculum. All chemistry content is developed through everyday life contexts such as: *Chemistry of life* or *Minerals and medicine.*

Table 6 provides a structure, outlining how the context (the 'storyline') in the Salters curriculum is connected to the content and students' activities. (For a parallel example on the same topic from Israel, using the context of industrial case studies, see Hofstein and Kesner, 2006.) Today, starting from the Salters experience a new CB approach has been developed by the same institute under the headline 21st Century Science (Millar, 2006), which strongly connects the CB approach with more societal driven curricula.

Table 6. Sketch from a Salters curriculum unit

Activities	***Chemical storyline***	***Chemical ideas***
	Why is the sea so salty? – A story of smokers and solutions	Ions in solids in solution (precipitation and ionic equations) Concentrations of solution
Writing the formulae of ionic compounds Solutions of ions	The lowest point on earth	Atoms and ions Chemical bonding (using formulae) Ions and solids in solution (dissolving) Oxidation and reduction The p-block: group 7 Electronic structure, sub-shells and orbitals
	An industrial case study – how best to manufacture chlorine	The operation of chemical manufacturing process Raw materials Costs and efficiency Plant location Health and safety Waste disposal
Which is the most cost-effective brand of bleach? What do the halogens look like? This liquid is dangerous Reactions of halogens and halides Check your knowledge and understanding	From atomic bombs to safer drinking water	Chemical bonding (bond polarity and electronegativity) Forces between molecules: temporary and permanent dipoles The p-block: Group 7
Finding the concentration of an acid solution Manufacturing halogens and their compounds	Hydrochloric acid – an industrial success	Concentration of solutions (titrations) Percentage of yield and atom economy (atom economy)
Nucleophilic substitution reaction mechanism How do halogenoalkanes differ in reactivity? Making of halogenalkane	Treasures of the sea	Halogenalkanes Percentage yield and atom economy (percentage yield)
Check your knowledge and understanding	Summary	

Chemie im Kontext (ChiK). Being inspired by the Salters project, the project *Chemie im Kontext (ChiK)* started in Germany in the 1990s. Three theoretical components underpin the philosophy of ChiK: an orientation on the concept of scientific literacy for all, the recognition of theories and evidence regarding motivation, and a thorough orientation on the theory of situated learning (Parchmann et al., 2006; Nentwig, Parchmann, Gräsel, Ralle, & Demuth, 2007). Even more so than Salters, ChiK is strongly built upon self-directed and co-operative forms of learning (see Chapter 7).

Teaching according to ChiK is conceptualised by three pillars: orientation on contexts, connection to basic concepts, and a variety of teaching methods (Nentwig et al., 2007). Orientation on contexts means that, similarly to Salters, relevant topics are chosen as the basis from which to start chemistry learning. The contexts should be meaningful to the students and stem from students' everyday lives, technology, or society. The contexts are the guiding element in the structuring of the lesson plans and thus for the whole curriculum. The contexts are thought to engage the students and provoke questions.

The connection to basic concepts ensures that the chemistry knowledge students have gained within an individual context is detached from the specific context. The de-contextualisation and networking leads to cumulative learning of the basic concepts. E.g. a context on "food" provokes questions which answers leads to certain chemical knowledge. This knowledge is elaborated upon in a variety of ways, until the questions are answered. The elaboration of a context on burning will use some of this knowledge and produce some more. As context after context are explored, more knowledge is built up, and whenever elements of a basic concept emerge, they are reflected and used for systematic organising of the acquired knowledge. As a result, the structure of the curriculum is not in parallel to the structure of the discipline. A different logical structure of the content forms itself starting from different context, via de-contextualised pieces of theory, towards networked basic concepts (Figure 5).

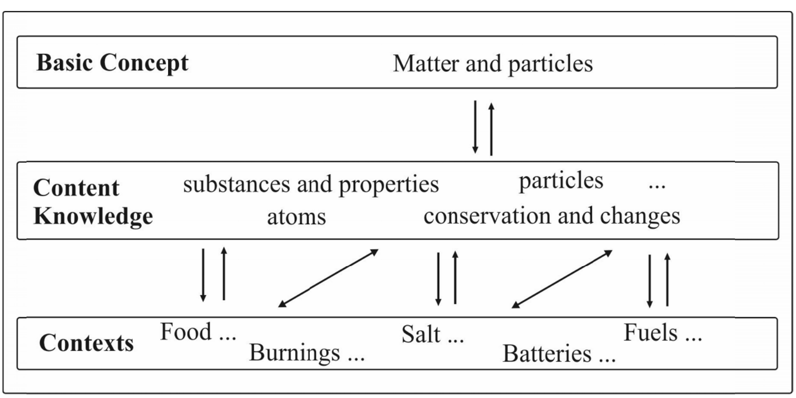

Figure 5. Building up basic concepts from different contexts

From the pedagogy, a lesson plan from ChiK is always subdivided into four stages (Table 7). In the first phase of contact the students are confronted with the context, e.g. table salt. Using most diverse materials, media and food for thought, the significance of context for everybody is illustrated. The ensuing phase of curiosity and planning is supposed to collect and structure the questions that arose in stage one in such a way that they can be addressed and answered appropriately within the third phase of elaboration. This stage aims to explore the students' questions in such a way that the necessary chemical expertise is facilitated. On the other hand students recognise the connection to the context and their own questions and perceive chemistry as helpful and meaningful for them. Within the final phase the content is examined in more depth and networked to other knowledge, interrelations to previously discussed contexts and learned content take place. This phase aims at the promotion of establishing cumulatively the basic chemical principles.

Table 7. The four phases of ChiK-lessons on the example of "Table salt – the white gold"

1. Phase of contact	Story: "Bread and salt – presents of the gods" Brainstorming on students ideas and prior-knowledge on the topic 'table salt'
2. Phase of curiosity and planning	Structuring with mindmaps, collecting students' questions, planning the work
3. Phase of elaboration	Learning at stations on the properties of table salt and ionic bonding
4. Phase of deepening and networking	Presentations with posters and experiments on the different aspects of table salt, networking the content with other knowledge, e.g. atomic structure and bonding

A large implementation programme accompanied the curriculum development with working groups of teachers. ChiK combined the development of teaching units, the implementation in schools, and the professional development of teachers. By the end of 2008, more than 200 teachers and more than 4000 students in Germany participated in the project, while many more probably used the ChiK material.

Socio-scientific issues based chemistry teaching

In the previous section we discussed how learning chemistry can be embedded in the contention for utilising contexts from everyday life or society to make learning more motivating and sustainable. The movement of socio-scientific issues-based chemistry education (SSI) goes even one step further. The context is no longer understood as a framework for the learning of chemistry. In SSI curricula the societal issue itself becomes the content of the lesson. Socio-scientific issues are used to understand how society is dealing with questions from within the society while having a fundamental basis in science and technology (e.g. Sadler, 2011).

Of course, in SSI teaching societal contexts are chosen based on chemistry, science and technology. Furthermore, SSI chemistry education uses societal issues which are controversial in nature. Issues are chosen from which a societal decision, which has an impact on the students' life or the development of society, must be made. The major objective is to learn how society is dealing with such controversial issues and how the individual can participate on societal debate and decision about them.

One example of SSI approaches is the socio-critical and problem-oriented approach to chemistry teaching as suggested by Marks and Eilks (2009). Lesson plans following the socio-critical and problem-oriented approach to chemistry teaching are always authentic, controversial and will have direct impact on life in society. Topics are political decisions on taxes for renewable energy sources, restrictions in production and use of specific goods where the use may have an impact on the environment or health, or how advertisements, pressure groups or politicians deal with a socio-scientific issue in a societal debate (Eilks et al., 2012).

One example may illustrate this approach, a lesson plan on low-fat and low-carb-diets (Marks, Bertram, & Eilks, 2008). In the public different forms of diets are suggested. Advertisements are present for light products containing less fat. Nevertheless, there is no scientifically clear proof as to whether these diets work and work well. Starting from authentic advertisements for light potato crisps and conventional crisps, students start reflecting what the advertising is about, what the promise is, or whether the arguments are true from a chemistry point of view (e.g. the calorie content). Chemical investigations about the fat content of different sorts of potato crisps and calculations about the calorie value are motivating the students learning about the chemistry behind the topic. The chemistry covers the occurrence and structure of fats and carbohydrates. Unlike the pure CB curricula the lesson plan does not stop here. The lesson continues to examine how the issue is handled in a societal debate. In this case, a role play mimicking a TV-talk show on low-fat- and low-carbohydrate-diets is added. The students learn that different stakeholders (producers of crisps, producers of light products, nutrition experts, or public relations experts) are arguing about their position towards the issue. The students learn that in order to understand the issue background knowledge in science is necessary. But, the students also learn that the information directed towards the consumer is always filtered by individuals who are promoting their interests (Eilks et al., 2012). The students learn that science can be the basis for understanding a topic, but that decisions about such an issue always are influenced by different interest groups and that a decision on e.g. the consumption of potato crisps in most cases is influenced by a whole conglomerate of arguments of which only a few stem from the scientific base of the issue.

Marks and Eilks (2009) developed a whole set of this kind of lesson plans. All follow a joint educational model (Figure 6). Criteria for selecting such

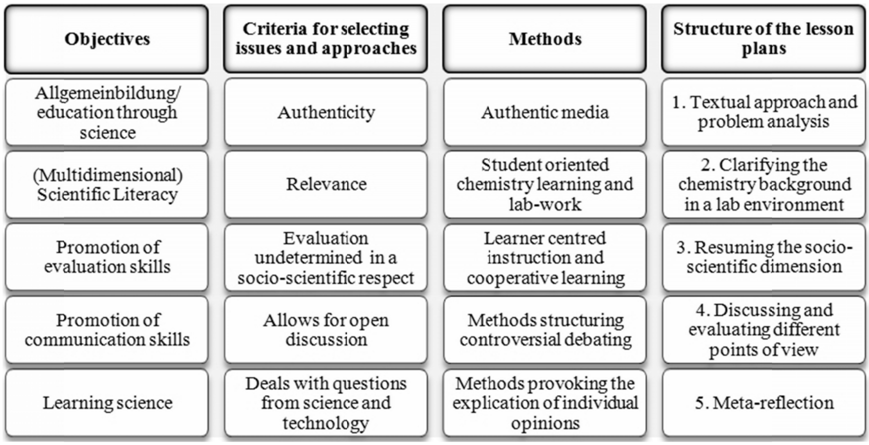

Figure 6. The socio-critical and problem-oriented approach to chemistry teaching

controversial issues are discussed earlier in this chapter. But, the model also gives guidance for the pedagogy, e.g. by the use of authentic materials from newspapers, brochures, or TV and the use of student-active methods for learning the background science but also for learning about how chemistry is handled in society. Such methods can encompass role-play and business games. However, the writing of news-spots for a fictional TV-show on a controversial issue (see Chapter 7) or the mimicking of a consumer test (see next section) can also be examples. Another example in Table 8 on bioethanol usage is given for illustrating the different steps and the pedagogy.

Through evaluating the different examples such an approach it was found that it proved to be very motivating for the students. The students learned how difficult societal decisions about questions regarding the application of science and technology can be. But, the students also learned about how society is conducting this debate and how a democratic decision making process is enacted.

Education for Sustainable Development (ESD) and chemistry teaching

The philosophy of *Education for Sustainable Development (ESD)* by principle is interdisciplinary in nature. Its interdisciplinary nature as well as the present and future relevance of the sustainability debate, with all its inherent dilemmas, uncertainties and confusions, constitutes a fertile ground for education (Rauch, 2002). All school subjects are asked to contribute to ESD – also chemistry (Burmeister et al., 2012). But, fitting ESD objectives and the chemistry syllabus together is not always easy. Here we will present an example of how ESD can be included into the regular chemistry curricula. But we also will discuss the potential role ESD may have for school development.

Table 8. Example for a socio-critical and problem-oriented lesson plan on bioethanol usage (Feierabend & Eilks, 2011)

1. Textual approach and problem analysis	The students read and analyse an authentic article from a political magazine reporting the growing use of bioethanol as fuels and critically mentioning potential side effects such as cutting down rain forests and a rise in food prices on the world market.
2. Clarifying the chemistry background in a lab-environment	The students learn about the structure of alcohols, fermentation, and the problems and benefits of the use of alcohols as fuels in cars, by using the cooperative mode of a jigsaw classroom in combination with a learning at stations lab.
3. Resuming the societal debate	A joint reflection leads to the understanding that the chemistry background might be sufficiently clear. But, the base for a political decision also will have to include consideration of ecological, economical and social effects.
4. Discussing and evaluating different points of view	A parliaments' hearing is mimicked in a role play. The preparation and presentation explicates the different arguments and points of view of different stakeholders from within society.
5. Meta-reflection	A meta-reflection on the debate highlights the different roles of scientists, pressure groups and politicians, makes clear the complexity of the decision, and also shows how society is handling such decision making.

ESD within the chemistry curriculum. Coming from a societal point of view Burmeister and Eilks (2012) described an example about how to implement ESD type teaching within typical chemistry curricula. The lesson plan was inspired by the socio-critical and problem-oriented approach to chemistry teaching (see previous section). The lesson plan is focussing on learning about general principles of sustainability and is following the pedagogy of ESD.

The lesson plan uses the debate about the extensive use of plastics in our current society. The benefits of plastics are mainly the cheap and practical use of plastics; this is confronted and examined in the context of the growing amounts of plastics waste in the environment and the social problems of exporting waste from the Western world to poorer countries. Taking into consideration the multi-dimensional effects of plastics usage, an evaluation is complex. The use of different sorts of conventional plastics, or the search for alternatives, like bio-plastics from starch, have to be evaluated by many means, not only by looking at the practical dimension of synthesis and properties.

That is why the lesson plan goes beyond confronting the students with essential chemistry of polymer production, investigations of their properties or the synthesis of bio-plastics. The lesson plan operates a specific method to allow students to learn that an evaluation with respect to sustainability has to use and find a balance between different dimensions, i.e. the practicability and worth of its use, but also the economical, ecological and social effects of production, use and deposition. In this case the students mimic the work of a consumer test agency. The students have to find out about and negotiate the different dimensions and aspects that will influence the overall evaluation. The students have to decide how big the percentage value is in terms of how to weight each of the dimensions and what their influence on the overall evaluation should be. Those dimensions often conflict with each other. A change in the weighing might influence the result even more than a different value in one of the dimensions.

In the end a decision has to be made. The decision is about a product from science and technology. But the students start recognising that in most cases the result is at least as much influenced by economical or ethical reasons (Table 9).

Table 9. Example for an ESD driven lesson plan on evaluating plastics (Burmeister & Eilks, 2012)

1. Textual approach and problem analysis	The problem of plastic waste in the environment is used to open debate about different sorts of plastics (e.g. PVC or PET) and the alternative of bio-plastics (e.g. TPS).
2. Clarifying the chemistry background	The chemistry of polymer production from crude oil and renewable resources is learned about, as well as different properties of different sorts of plastics are evaluated.
3. Resuming the different dimensions of evaluation	Reflection shows that investigating plastics in a chemistry lab can only focus their properties, potential use and degradability. Science cannot answer questions about economical and social effects of plastics production and usage.
4. Discussing and evaluating by the different ESD dimensions	A consumer test is mimicked, encompassing the practical dimension of plastics production and usage. But, the test also has to consider the economical, ecological and social impacts. Students have to decide about valuing the different effects and about weighing the different dimensions in relation of one to another.
5. Meta-reflection	In the end, it is reflected that is always the individuals that have to decide about giving the different values in the dimensions and of weighing the dimensions in competition of one to another.

ESD and chemistry for school development. ESD is an interdisciplinary and cross-curricular challenge. That is why a serious contention triggers the whole school including teaching and learning in all subjects. Such a broad view of implementing ESD into the practice of teaching was the focus of different national and international projects of school development, e.g. the ENSI project (www.ensi.org) or BLK-21 and Transfer 21 from Germany (www.transfer-21.de). The philosophy in these projects was an understanding that all school's life and teaching should become part of ESD. That means, all school stakeholders were asked to explore challenges of the future, to clarify values and to reflecting on learning and taking action in the light of ESD.

ESD in terms of school development understands the school as a learning organisation. It should stimulate new ways of challenging the school climate and all internal relationships. ESD for school improvement understands the school's culture as an expression of the school's collective 'memory.' Thus new experience, reflections, innovations etc. have to be made to change the way people interact, discuss and act. Such an approach encourages the integration of ESD in the normal life of the school and considers engagement in ESD not as an extra burden for teachers and headmaster, but as an opportunity for improving the existing teaching and learning and to provide innovations useful for the whole school (Breiting, Mayer, & Mogensen, 2005).

This means that chemistry teaching should also contribute to such a changed culture of teaching (Burmeister et al., 2012). Opportunities are present to open chemistry teaching to societal points of view and to reflect upon how chemistry is influencing us, in our life outside and inside of school. Chemistry teaching following an ESD point of view should focus on how to save resources (energy, clean water, …) or how to treat waste in a potentially good way for later recycling in the society as a whole or within the school in particular. External contacts to local energy or water suppliers or the waste and waste water treatment companies can help to better understand how chemistry is embedded into our everyday life, economy and ecology.

But, ESD as part of a school's culture should not stop with learning about it. Students should learn how action can promote implementation leading to a more responsible handling of our resources and how to do it. Then it is a joint decision of the whole school as to whether to and how to change behavior, of which the learning process in chemistry was a preparation for. In this way, also chemistry teaching can contribute implementing changed behaviours and processes within the school and beyond by a democratic process of negotiation, conviction and decision (Burmeister et al., 2012).

SUMMARY: KEY SENTENCES

– Students' interest in studying chemistry can be due to very different reasons. Individual interest can range from the learning of chemistry theory as the best possible start for a later career in science and engineering towards becoming prepared for participation in society as a future citizen.
– Different structures of the chemistry curriculum offer a broad range of approaches between mirroring the academic discipline and history of chemistry

towards being an area to promote general educational objectives in the context of the societal dimension of chemistry.

- The theory of the curriculum emphases offers a base for reflecting upon the main objectives behind a curriculum. Theories of Allgemeinbildung, Scientific Literacy, Activity Theory, or Situated Cognition offer guidance for structuring the curriculum.
- Compulsory chemistry education curricula should meet the needs of the majority of the students that is to learn essential science for everyday life coping and becoming prepared for societal participation in questions concerning science, technology, and sustainability.
- Approaches towards chemistry learning starting from contexts or societal issues that are meaningful for the learner, proved to be more effective for the learning of chemistry than the pure science structured curricula.

ASK YOURSELF

1. Outline: What do we mean by 'scientific literacy for all' and by 'relevance' in the context of chemistry education?
2. Explain the basic ideas of the theory of the curriculum emphases. Name and explain the three dominant curriculum emphases in modern chemistry teaching as outlined by Van Berkel.
3. Describe the basic ideas of structure of the discipline (SOD) and history of science (HOS) curricula. What are the strengths and what are the weaknesses of these two curriculum approaches in chemistry education?
4. Outline the basic ideas, commonalities and differences between context-based and socio-scientific issues-based chemistry education.
5. Outline three different proposals of how to teach the topic of 'ethanol/alcohols' in secondary chemistry using (i) an everyday life perspective, (ii) a societal/ESD perspective, and (iii) an industrial perspective.

HINTS FOR FURTHER READING

Coll, R., & Taylor, N. (2009). Special Issue on Scientific Literacy. *International Journal of Environmental and Science Education, 4*(3), 197-349. The special issue offers different contributions of how to understand the idea of scientific literacy for all and how to operationalize respective science teaching.

Hodson, D. (2009). *Teaching and learning about science*. Rotterdam: Sense. An account of presenting the science curriculum by using a nature of science approach is presented acknowledging scientists as a socially, economically and politically important community of people with its own language, methods, traditions, norms and values.

Pilot, A., & Bulte, A. M. W. (2006). Special Issue: Context-based chemistry education. *International Journal of Science Education, 28*(9), 953-1112. An overview about context-based chemistry teaching is given and illustrated by different examples form a variety of countries.

Aikenhead, G. S. (2006). *Science education for everyday life*. Columbia: Teachers College Press. The book offers a review humanistic and societal driven science education illustrated by examples from research and practice.

Sadler, T. D. (2011). *Socio-scientific issues in the classroom.* Heidelberg: Springer. The book sums up the different facets of socio-scientific issues based science education and offers guidance how to implement it into the classroom.

Eilks, I., & Rauch, F. (2012). Special Issue: Education for Sustainable Development and Green Chemistry in chemistry education. *Chemistry Education Research and Practice, 13*(2), 53-153. Theoretical and practical papers examine the state of the art in ESD driven chemistry education.

RESOURCES FROM THE INTERNET

D. Warren: The Nature of Science at www.rsc.org/images/Nature%20of%20 Chemistry_tcm18-188306.pdf. This online resource offers many resources and ideas to implement the Nature of Science (NoS) into the chemistry curriculum.

21st Century Science: www.nuffieldfoundation.org/twenty-first-century-science. A current curriculum development project from the UK is presented. Materials are offered for context-based and scientific literacy oriented science education.

PARSEL: Popularity and Relevance of Science Education for Scientific Literacy: www.parsel.uni-kiel.de/cms/. Different modules of societal and everyday-life driven lesson plans are presented in different languages.

PROFILES: Professional Reflection-oriented Focus on Inquiry-Learning and Education through Science Literacy: www.profiles.eu. As being a spin-off of PARSEL more and newer lesson plans are presented.

UNESCO: World Decade of Education for Sustainable Development: www.unesco.org/en/esd/decade-of-esd/. Political papers and guidelines are given how to implement ESD driven education into practical teaching.

REFERENCES

American Association for the Advancement of Science (AAAS) (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

Atkin, M. J., & Black, P. J. (2003). *Inside science education reform*. New York: Teachers College Press.

Benett, J., & Lubben, F. (2006). Context-based chemistry: The Salters-approach. *International Journal of Science Education, 28*, 999-1015.

Black, P. J., & Atkin, J. M. (1996). *Changing the subject: Innovations in science, mathematics and technology education*. London: Routledge.

Breiting, S., Mayer, M., & Mogensen, F. (2005). *Quality criteria for ESD-schools.* Vienna: ENSI.

Bruner, J. (1962). *The process of education*. Harvard: Harvard University.

Burmeister, M., & Eilks, I. (2012). Evaluating plastics to promote Education for Sustainable Development (ESD) in chemistry education. *Chemistry Education Research and Practice, 13*, 93-102.

Burmeister, M., Rauch, F., & Eilks, I. (2012). Education for Sustainable Development (ESD) and secondary school chemistry education. *Chemistry Education Research and Practice, 13*, 59-68.

De Boer, G. E. (1991). *A history of ideas in science education*. Columbia: Teachers College Press.

De Jong, O. (2006). Making chemistry meaningful: conditions for successful context-based teaching. *Educación Química*, *17*, 215-226.

Duranti, A., & Goodwin, C. (eds.). (1992). *Rethinking context: Language as an interactive phenomenon.* Cambridge: Cambridge University.

Eilks, I. (2002). Teaching 'Biodiesel': A sociocritical and problem-oriented approach to chemistry teaching, and students' first views on it. *Chemistry Education Research and Practice, 3*, 67-75.

Eilks, I. (2012). Teachers' ways through the particulate nature of matter in lower secondary chemistry teaching: A continued change of different models vs. a coherent conceptual structure? In G. Tsaparlis & H. Sevian (eds.), *Concepts of matter in science education*. Dordrecht: Springer (forthcoming).

Eilks, I., Nielsen, J. A., & Hofstein, A. (2012). Learning about the role of science in public debate as an essential component of scientific literacy. In C. Bruguière, P. Clément, & A. Tiberghien (eds.), *Book of selected presentations, ESERA Conference Lyon 2011* (forthcoming).

Elmose, S., & Roth, W.-M. (2005). Allgemeinbildung: Readiness for living in a risk society. *Journal of Curriculum Studies, 37*, 11-34.

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

Gilbert, J. K. (2006). On the nature of context in chemical education. *International Journal of Science Education*, *28*, 957-976.

Greeno, J. G. (1998). The situativity of knowing, learning, and research. *American Psychologist, 53*, 5-26.

Harms, N. C., & Yager, R. E. (1981). *What research says to the science teacher*. Washington: NSTA.

Hart, C. (2002). Framing curriculum discursively: Theoretical perspectives on the experience of VCE physics. *International Journal of Science Education,* 24, 1055-1077.

Hodson, D. (2008). *Towards scientific literacy: A teachers' guide to the history, philosophy and sociology of science.* Rotterdam: Sense.

Hofstein, A., Eilks, I., & Bybee, R. (2011). Societal issues and their importance for contemporary science education: A pedagogical justification and the state of the art in Israel, Germany and the USA. *International Journal of Science and Mathematics Education, 9*, 1459-1483.

Hofstein, A., & Kesner, M. (2006). Industrial chemistry and school chemistry: Making chemistry studies more relevant. *International Journal of Science Education*, *28*, 1017-1039.

Holbrook, J. (1998). Operationalising scientific and technological literacy – A new approach to science teaching. *Science Education International, 9,* 13-18.

Holbrook, J., & Rannikmäe, M. (2007). The nature of science education for enhancing scientific literacy. *International Journal of Science Education*, *29*, 1347-1362.

Holman, J. (1986). *Science and technology in society. General guide for teachers*. Hatfield Herts: ASE.

Holman, J. (1987). Resources or courses? Contrasting approaches to the introduction of industry and technology to the secondary curriculum. *School Science Review*, *68*, 432-437.

Johnstone, A. H. (1981). Chemical education research-facts, findings and consequences. *Chemistry in Britain*, *17*, 130-135.

Johnstone, A. H. (2006).Chemical education in Glasgow in perspective. *Chemistry Education Research and Practice*, *7*, 49-63.

Justi, R., & Gilbert, J. K. (2002). Models and modeling in chemical education. In J. K. Gilbert, O. de Jong, R. Justi, D. F. Treagust, & J. H. Van Driel (eds.), *Chemical education: Towards research-based practice* (pp. 47-68). Dordrecht: Kluwer.

Keller, J. M. (1983). Motivational design of instruction. In C. M. Reigeluth (ed.), *Instructional design theories: An overview of their current status* (pp. 386-434). Hillsdale: Lawremce Erlbaum.

KMK (2004). *Bildungsstandards im Fach Chemie für den Mittleren Bildungsabschluss*. München: Luchterhand.

Kyburz-Graber, R., Nagel, U., & Odermatt, F. (eds.) (2010). *Handeln statt hoffen. Materialien zur Bildung für Nachhaltige Entwicklung für die Sekundarstufe 1.* Zug: Klett.

Marks, R., & Eilks, I. (2009). Promoting scientific literacy using a socio-critical and problem-oriented approach to chemistry teaching: Concept, examples, experiences. *International Journal of Science and Environmental Education, 4*, 131-145.

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

Mc Comas, W. F. (2004). *The nature of science in science education*. Dordrecht: Kluwer.

Merrill, R. J., & Ridgway. D. W. (1969). *The CHEMStudy curriculum improvement project*. San Fransisco: W. H. Freeman.

Millar, R. (2006). Twenty-first century science: insights from the design and implementation of a scientific literacy approach in school science. *International Journal of Science Education*, *28*, 1499-1521.

Nentwig, P., Parchmann, I., Gräsel, C., Ralle, B., & Demuth, R. (2007). Chemie im Kontext – A new approach to teaching chemistry, its principles and first evaluation data. *Journal of Chemical Education, 84*, 1439-1444.

Newton, D. P. (1988). Relevance and science education. *Educational Philosophy and Theory*, *20*(2), 7-12.

National Curriculum (2004). *National Curriculum handbook for secondary teachers in England*. London: QCDA.

NRC (National Research Council) (1996). *National science education standards*. Washington: National Academy Press.

OECD (2006). *OECD programme for international studies assessment (PISA) on line*. www.pisa.oecd.org/dataoecd/30/17/39703267.pdf.

Parchmann, I., Gräsel, C., Baer, A., Nentwig, P., Demuth, R., & Ralle, B. (2006). Chemie im Kontext – A symbiotic implementation of a context-based teaching and learning approach. *International Journal of Science Education*, *28*, 1041-1062.

Pilot, A., & Bulte, A. M. W. (2006). The use of "contexts" as a challenge for the chemistry curriculum: Its successes and the need for further development and understanding. *International Journal of Science Education*, *28*, 1087-1112.

Rauch, F. (2002). The potential of Education for Sustainable Development for reform in schools. *Environmental Education Research, 8*, 43-52.

Rauch, F. (2004). Education for sustainability: A regulative idea and trigger for innovation. In W. Scott & S. Gough (eds.), *Key issues in sustainable development and learning: A critical review* (pp. 149-151). London: Roudlege Falmer.

Reid, N. (2000). The presentation of chemistry logically or application-led. *Chemistry Education Research and Practice*, *1*, 381-392.

Roberts, D. A. (1982). Developing the concept of "curriculum emphasis" in science education. *Science Education, 66*, 243–260.

Rutherford, F. J., & Ahlgren, A. (1989). *Science for all Americans: The project 2061*. New York: Oxford University.

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research Science Teaching*, *41*, 513-536.

Sadler, T.D. (2011). *Socio-scientific issues in the classroom*. Heidelberg: Springer.

Sadler, T. D., & Zeidler, D. (2009). Scientific literacy, PISA, and socioscientific discourse: Assessment for progressive aims of science education. *Journal of Research in Science Teaching*, *46*, 909-921.

Schwartz, A. T. (2006). Contextualized chemistry education: The American experience. *International Journal of Science Education, 28*, 977-998.

Solomon, J., & Aikenhead, G. (eds.) (1994). *STS education: international perspectives on reform*. New York: Teachers College Press.

UNESCO. (2006). *Framework for the UNDESD international implementaton scheme.* Paris: UNESCO.

Van Berkel, B. (2005). *The structure of current school chemistry*. Utrecht: cdβ.

Van Berkel, B., De Vos, W., Verdonk, A. H., & Pilot, A. (2000). Normal science education and its dangers: The case of school chemistry. *Science* & *Education, 9*, 123-159.

Van den Akker, J. (1998). The science curriculum: Between ideals and outcomes. In B. Fraser & K. Tobin (eds.), *International Handbook of Science Education* (pp. 421-447). Dordrecht: Kluwer.

Van Driel, J. H., Bulte, A. M. W., & Verloop, N. (2007). The relationship between teachers' general beliefs about teaching and learning and their domain specific curricular beliefs. *Learning and Instruction*, *17*, 156-1717.

Wandersee, J. H., & Baudoin Griffard, P. (2002). The history of chemistry: Potential and actual contributions to chemical education. In J. K. Gilbert, O. De Jong, R. Just, D. F. Treagust, & J. H. Van Driel (eds.), *Chemical education: Towards research-based oractice* (pp. 29-46). Dordrecht: Kluwer.

Ware, S., & Tinnesand, M. (2005). Chemistry in the Community (ChemCom): Chemistry for future citizens. In P. Nentwig, & D. Waddington (eds.), *Making it relevant: Context-based learning of science* (pp. 91-120). Münster: Waxmann.