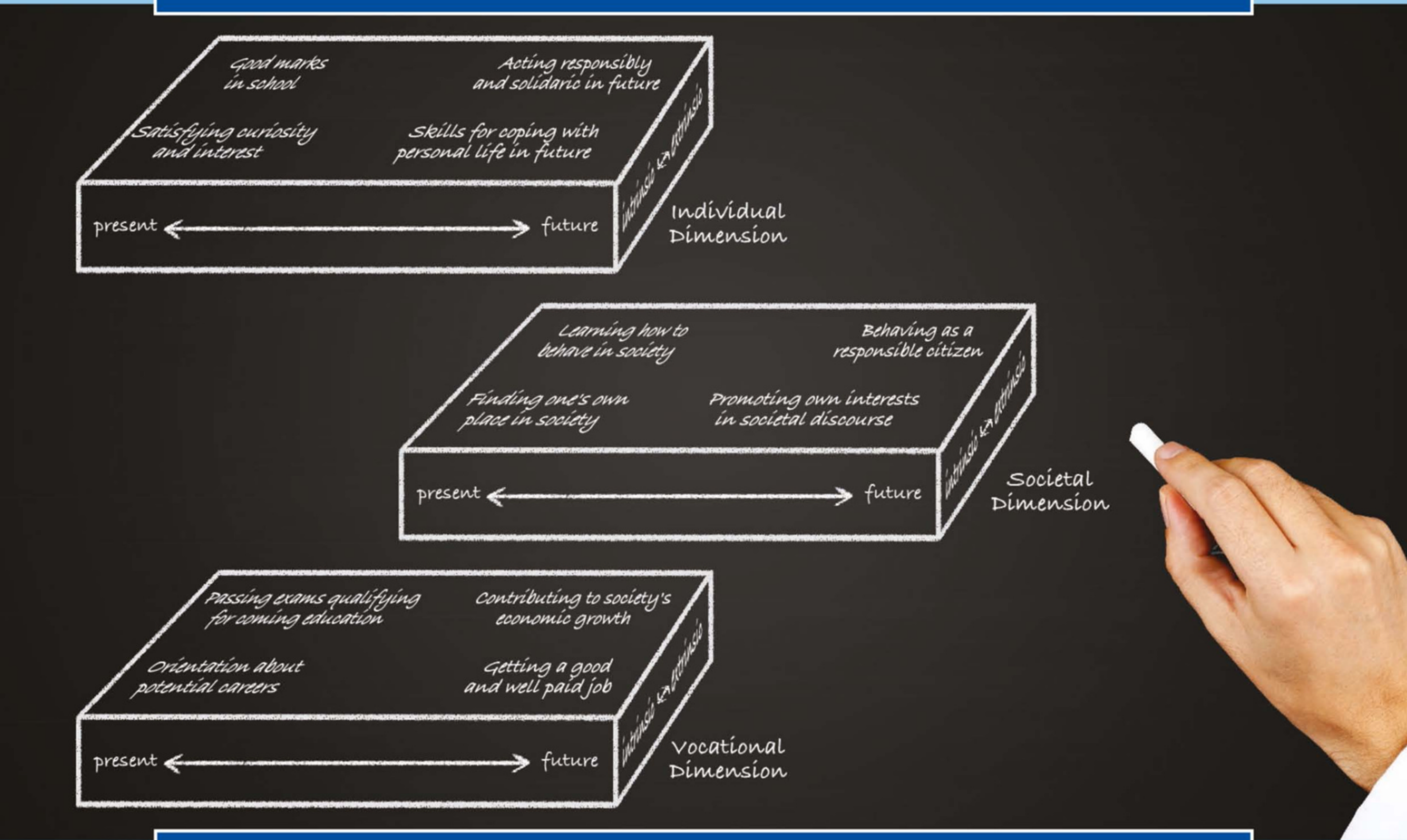
Relevant Chemistry Education

From Theory to Practice

Ingo Eilks and Avi Hofstein (Eds.)



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INGO EILKS AND AVI HOFSTEIN

1. FROM SOME HISTORICAL REFLECTIONS ON THE ISSUE OF RELEVANCE OF CHEMISTRY EDUCATION TOWARDS A MODEL AND AN ADVANCE ORGANIZER – A PROLOGUE

Many studies and educational policy papers present a gloomy picture with respect to the learning of chemistry, especially at the secondary school level. A key claim is that science education – particularly in chemistry – is unpopular among many students. The claim infers that students are insufficiently interested in chemistry learning. One of the reasons mentioned quite frequently is that learners do not perceive chemistry and chemistry education as relevant both for themselves and for the society in which they live. Current educational policy suggests that chemistry teachers must make chemistry education "more relevant" in order to better motivate their students and interest them in chemistry studies. However, it remains unclear what making chemistry learning more relevant actually entails. This book focuses on the relevance of chemistry education. It was inspired by a recently suggested definition and model of the relevance of science education in its adjustment to the teaching and learning of chemistry. This introduction provides the reader with the definition and the model as well as an overview of the chapters in this book.

INTRODUCTION

In recent years, many studies have been conducted and corresponding articles published that clearly present a rather a gloomy picture with respect to the learning of science, especially at the secondary school level. A key claim is that science education – particularly in physics and chemistry – remains unpopular among many students (Dillon, 2009; Gilbert, 2006; Hofstein, Eilks, & Bybee, 2011; Holbrook, 2008; Osborne & Dillon, 2008). Based on that premise, it is suggested that science teachers should make science education "more relevant" in order to better motivate their students and interest them in science subjects (Holbrook, 2003; 2005), which has already been claimed since the 1980s (Newton, 1988a & b). However, in all these papers very often it remains unclear what making science learning more relevant actually entails. This uncertainty encompasses both the issue of how this goal can be attained and determining which connections (or differences) exist among terms such as relevance, interest, needs matching,

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meaningfulness, usefulness, and motivation (for more details see Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013).

Many publications emphasize the relevance of science education (and chemistry education in particular) in order to maintain the economic wealth of modern societies, thereby justifying science skills among the young generation as essential for continued prosperity in our future (Bradley, 2005). The voices advocating that science knowledge and skills need to be strengthened mainly come from those interested in promoting economy, businesses, and industry. Many related sources claim that modern societies need to actively invest a sufficient amount of their educational resources in students who will potentially embark on careers in science and technology and in motivating them to do so (EC High Level Group, 2004). Today, every developed and emerging country needs more scientists to achieve additional scientific and technological developments and to maintain future economic standards of living (EC High Level Group on Science Education, 2007).

Other voices emphasize that scientific literacy is needed for all future citizens in order to influence techno-scientific developments in a democratic society for more sustainability (Burmeister, Rauch, & Eilks, 2012) and to enable all citizens to actively and intelligently participate in societal debates concerning any controversial socio-scientific issues (Roth & Lee, 2004). On this basis, it is reasonable to assume that all students need a certain level of scientific knowledge and related skills in order to become scientifically literate citizens and, thus, to be able to participate in dialectical socio-scientific discussions, debates, and decision-making processes. This is especially important in our increasingly technological world (Hofstein et al., 2011). In addition, this claim supports the idea of making science education more effective and relevant, but justifies investing in science learning from a different pedagogical perspective.

From both discussed perspectives, the following question arises: Can we equate the word "relevance" used to justify science education with the importance of science in a techno-scientific world, including its related applications with regard to ecological, economic, and societal developments as described in the rhetoric and practices of many educational policy papers? Or alternatively: Are there other justifications that can make science education relevant – but relevant for what purpose and for whom?

In pedagogical debates in science education the term relevance is used quite often and with various connotations (Stuckey et al., 2013). Apparently, explicit and generally accepted definitions and models of what is meant by relevance are still lacking in science education in the context of research as well as in educational policy, science curriculum planning, classroom development, and implementation of educational reform.

The current book focuses on the relevance of chemistry teaching and learning. There is no doubt that chemistry is economically and ecologically very important for sustaining our world and for every developed, emerging or less developed society (Bradley, 2005; Knamiller, 1994). However, the development and implementation of chemistry curricula and practices is influenced by different, often conflicting, stakeholders. These stakeholders differ in their views, goals, and objectives of what makes teaching and learning chemistry relevant, and their points of view vary because their roles in society are often completely different.

This introduction will sum up some essential points from a recently published paper by Stuckey et al. (2013) about the meaning of relevance in science education and its implications for the science curriculum. This paper was published in the journal *Studies in Science Education* as an analytical review, focusing on the meaning of relevance in the context of science education in general, and its related curricula, in particular. In our introduction, we will focus on secondary and undergraduate chemistry education. More specifically, we will present Stuckey et al.'s definition and model of how to understand relevance in science education as it was suggested in their paper. We suggest using this model in its application to chemistry education in order to provide readers with a resource to facilitate their orientation in the present book.

TOWARDS ACHIEVING AN UNDERSTANDING OF RELEVANCE IN SCIENCE EDUCATION

About twenty-five years ago, Newton (1988a) wrote about the question of relevance in science education:

> Science teachers are increasingly exhorted to make their teaching relevant but, in general, the notion of relevance in science education seems fraught with inconsistency, obscurity and ambiguity. (p. 7)

And that:

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

It appears that any definition or meaning applied to the term relevance often lacked clarity when it was used in the rhetoric of science education and in the context of curriculum reform up to the 1980s. Newton (1988a), for example, in describing England's school curriculum, reported that teachers are required to teach more "relevant" science. However, his concern was that the curriculum descriptors did not define what was meant by relevant science. Newton (1988b) suggested that relevance means reflecting upon science education's relation to three concerns: products, processes, and people. Knamiller (1984), however, showed that at the same time different understandings also emerged. He linked his understanding of relevance to the question of economic development and growth of societies, whereas additional authors, like Keller (1983), linked relevance to fulfilling personal needs, and so on.

The recent review of the literature by Stuckey et al. (2013) revealed that the use of the term relevance in conjunction with science education is still manifold and is not coherent. They suggested that there are five different basic understandings of the term relevance in the literature in the context of science education, and that clearly distinguishing between them is not always possible and in several papers different understandings merge. The five basic understandings found in the literature are as follows:

- Relevance used as a synonym for student interest (e.g. Ramsden, 1998; Childs, 2006).
- Relevance understood as students' perception of meaningfulness by embedding science learning into contexts connected to students' lives, industry, or technology (e.g. Gilbert, 2006; King, 2012; Lyons, 2006; Mandler, Mamlok-Naaman, Blonder, Yayon, & Hofstein, 2012).
- Relevance in terms of meeting student needs, which can be understood as usefulness or needs matching (e.g. Keller, 1983; Simon & Amos, 2009).
- Relevance viewed in the sense of real-life effects for individuals and society, e.g., in terms of growing prosperity and sustainable development by applying science and technology to societal, economic, environmental, and political issues (e.g. De Haan, 2006; Hofstein & Kesner, 2006; Knamiller, 1984) but also in a way that it might concern individual decisions that impact students' lives directly (e.g. Marks & Eilks, 2009; Stolz, Marks, Witteck, & Eilks, 2014).
- Relevance viewed multi-dimensionally and applied as a combination of selected elements borrowed from all the above categories (e.g. Newton, 1988a, 1988b; Aikenhead, 2003).

The analysis by Stuckey et al. (2013) revealed that relevance of science education has different dimensions. But which dimensions does it necessarily encompass? One point of view is, as stated by Knamiller (1984), the economic development of society. Therefore, a shift to relevant chemistry education can be linked to and influenced by economic constraints. This also influences the curriculum in terms of the availability of funds for reforms and its related curriculum development. For example, Eijkelhof and Kortland (1988) in the Netherlands described a curricular reform in the teaching of Physics: The PLON project. PLON was funded over a period of almost 15 years. This long-term curriculum development project provided continuous feedback to stakeholders (government and science educators) and encouraged them to broaden the goals of physics education from an academic and technological point of view towards achieving more relevance-oriented STS (Science-Technology-Society) teaching. There are many more examples in which curriculum development was influenced by future employers, such as industries or various academic institutions. In chemistry, industry was involved in the development of curricula, e.g. in Israel (Hofstein & Kesner, 2006) and in the UK (Bennett & Lubben 2006). The funds came from industries, with the goal in mind, of ensuring that in the future there will be enough competent employees in their industrial chemistry plants. In other words, it was expected that the contents of the subject matter would convince students to seek future careers in the chemical industry. However, scientists in academia who also influence curriculum development, e.g. by publishing policy or perspective papers in their journals or via academic societies, propelled the process more towards an approach having less societal and more academic emphasis, whereas academic stakeholders with a more general view on education promoted a more general educational skills-oriented paradigm for science education (Hofstein et al., 2011). Thus, it is clear that different stakeholders have different, sometimes conflicting, interests in curriculum orientation in science in general, and chemistry education, in particular. Students, their parents, teachers, and curriculum developers, as part of the formal school educational system, justify and promote certain topics and goals in the chemistry curriculum, just as external stakeholders do, e.g., the economy, industry, academia, and educational policy.

In considering all the different interests and points of view and by analyzing the science education literature over the last 50 years, Stuckey et al. (2013) suggested adopting a thoroughly outlined and multidimensional understanding of the relevance of science education. Their view was not mainly inspired by the different stakeholders' influence on the curriculum but instead by its effects on the student, the society, and the economy. Based on their analytical review of the literature, they suggested understanding the relevance of science education by focusing more on the idea of consequences. These consequences can be much broader than simply meeting the personally interests or perceived desires of the learner – they also cover the ability of the individual to live in a modern society and to responsibly participate in it, as well as to contribute to the economy and its development in the field of science and technology-related businesses.

Stuckey et al. (2013) suggested the following definition of relevance in the context of science education (adapted here for chemistry education):

- Chemistry learning becomes relevant education when the learning will have (positive) consequences for the student's life.
- Positive consequences can be:
  - (I) fulfilling the actual needs pertaining to the student's interests or educational requirements (that students will actually perceive), as well as
  - (II) anticipating future needs (that the students may not necessarily be aware of).
- The relevance of chemistry education covers both intrinsic and extrinsic components. The intrinsic dimensions encompass student's interests and motives; the extrinsic dimension covers ethically justified expectations of the personal environment or from society at large towards the student.
- Relevance can be considered as composed of different dimensions, an individual, a societal, and a vocational dimension. For science teaching this means that relevant science education contributes to students' intellectual skills development, promotes their competencies to participate in society today and in the future, and improves their vocational orientation and career choices.

Based on this definition, relevance in the context of science education is manifested in three dimensions: individual, societal, and vocational relevance. It was also pointed out that each of the three dimensions covers both intrinsic and extrinsic components, as well as present and future aspects. More specifically, these three dimensions consist of the following characteristics:

- *The individual dimension:* The individual relevance of science education for students encompasses matching the learners' curiosity and interests, providing students with requisite and useful skills for coping with their everyday lives today and in the future, and contributing to the development of intellectual skills.

- *The societal dimension*: The relevance of science education from the societal viewpoint focuses on preparing pupils for self-determined and responsibly-led lives in society by understanding the interdependence and interaction of science and society, developing skills for societal participation, as well as their ability to contribute to society's sustainable development.
- *The vocational dimension*: The relevance of science education in the vocational dimension consists of offering orientation for future professions and careers, preparing for further academic or vocational training, and opening up formal career opportunities (e.g. by having sufficient coursework and achievements in order to be accepted into any given higher education program).

These dimensions are not completely complementary or dichotomized; they are interrelated and partially overlap. For example, career orientation can either refer to personal curiosity or it can address a demand for more scientists and engineers in the future. The latter is directly linked to the idea of developing a prosperous and sustainable society.

Stuckey et al. (2013) also provided an illustrating model for the different dimensions of the relevance of science education (Figure 1) that can easily be adapted and interpreted for the domain of chemistry education, since it comprises part of science education in general. This model can serve as an advanced organizer for the various chapters in this book.

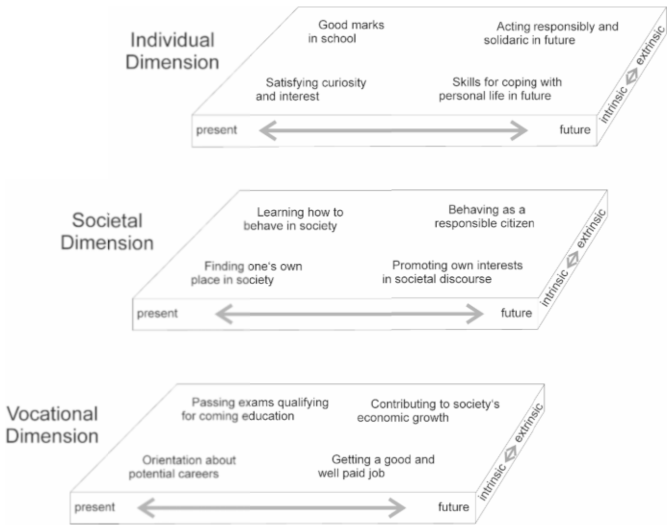

Figure 1. A model of the three dimensions of relevance with examples of aspects in both the present-future and the intrinsic-extrinsic ranges

A BOOK ON RELEVANT CHEMISTRY EDUCATION

The current book is aimed at chemistry teachers, teacher educators, chemistry education researchers, and all those who are interested in increasing the relevance of chemistry education as well as students' perception of it. It consists of 20 chapters written by more than 40 authors from 16 different countries. Each chapter focuses on a certain focus related to the issue of relevance of chemistry education as it is currently defined and the model of relevance discussed in the previous section.

The first two chapters of the book were written by Onno de Jong and Vicente Talanquer as well as Peter E. Childs, Sarah M. Hayes, and Anne O'Dwyer respectively. Both chapters focus on the relevance of science learning to individuals. De Jong and Talanquer clearly justify that it is highly relevant for every individual to have a basic understanding of the ideas of chemistry, whereas Childs, Hayes, and O'Dwyer outline where the learning of chemistry becomes relevant for better understanding and coping with everyday life issues.

The next two chapters, written by Hannah Sevian and Astrid M. W. Bulte as well as by Keith S. Taber, respectively, also focus mainly on the individual dimension of the relevance of chemistry education by considering whether and how the learning of chemistry needs to be contextualized. Sevian and Bulte make clear that contextualizing chemistry learning has the potential to enhance learners' motivation, and to strengthen the meaning of chemistry learning as well as its perception. Taber advocates a slightly different approach by clearly justifying that contextualized chemistry is only one side of chemistry learning, and that a more academic focus might be relevant to those learners specifically interested in chemistry as an academic endeavour in itself (or parts of it).

An additional set of three chapters discusses the role of chemistry education in contributing to the development of general educational skills and students' personal growth. They combine the individual dimension by focusing on personal skill development, but at the same time they advocate the view of empowering an individual as he behaves in society. Deborah Corrigan, Rebecca Cooper, and Stephen Keast suggest that science and chemistry teaching can play a significant role in students' learning about and developing values. Yehudit Judy Dori and Shirly Avergil discuss the role of metacognition during chemistry learning as relevant to individual skill development. And finally, in this set of chapters, Sibel Erduran and Aybuke Pabuccu provide examples and research-based evidence on how learning chemistry can provide a platform for developing argumentation skills that are important for exchanging information about science with others. All three chapters suggest that educational skill development by learning chemistry can help the individual to prepare for later participation in personal and societal contexts.

The next five chapters deal both with the personal and societal relevance of chemistry learning; however, they focus more on chemistry education's societal relevance. Jesper Sjöström, Franz Rauch, and Ingo Eilks discuss, in terms of education for sustainability, the importance of chemistry and chemistry education contributing to shaping society towards a sustainable future of our life, today and in the future. Such a societal focus also underpins the next two chapters, which deal with the communicational aspects of science in the public. Nadja Belova, Marc Stuckey, Ralf Marks, and Ingo Eilks provide the reader with a justification for why it is necessary, as well as different models, to learn about the science-to-society link and how information derived from science is introduced to the public and is used in societal debates by different stakeholders. A similar emphasis is provided by Shu-Nu Chang Rundgren and Carl-Johann Rundgren in discussing the role of science in the mass media and how chemistry education can contribute to the development of critical media literacy. An additional contribution in this section of the book are the issues of gender, culture, and minorities as relevant foci in the context of chemistry teaching, which is provided by Rachel Mamlok-Naaman, Simone Abels, and Silvija Markic. In addition, Andoni Garritz, Bruno Ferreira dos Santos, and Maria Gabriela Lorenzo reflect on shaping curricula to make chemistry learning relevant regarding chemistry education in non-Western socio-cultural environments.

Another set of four chapters takes the vocational and economic relevance of chemistry education into account. George Bodner provides a comprehensive overview regarding green chemistry, its history, and its role in education. This chapter starts by highlighting the vocational dimension of relevant chemistry education, but in addition, it justifies individual and societal relevance. This emphasis is expanded by Avi Hofstein and Miri Kesner to learning about chemical applications in industry, embedded in society. To directly learn about how chemistry operates in industry and business, Richard K. Coll introduces the concept of work-integrated learning in chemistry education. Following that, Jan Alexis Nielsen and Henriette Tolstrup Holmegaard project this aspect in the future by justifying that chemistry education is needed to shape the future by contributing to skills development in innovation and employability.

The final three chapters in this book leave the formal sector of secondary and undergraduate chemistry education. In recent years informal and non-formal education have become additional pillars in educational systems worldwide, achieving growing recognition and importance. This is discussed by Sakari Tolppanen, Jenni Vartiainen, Veli-Matti Ikävalko, and Maija Aksela for non-formal educational settings and by Sandhya D. Coll and David F. Treagust for the informal sector. Both in the formal as well as the informal/non-formal educational sectors there is an opportunity for chemistry educators to provide relevant, authentic, and the most up-to-date chemistry learning experiences for the students – and for the teachers to learn about them. This is why the book closes with a reflection by Muhamad Hugerat, Rachel Mamlok-Naaman, Ingo Eilks, and Avi Hofstein about what needs to be done in teacher education and continuous professional development in order to promote a sense of relevance in the chemistry classroom.

We sincerely hope that the readers of the book will be inspired by the different contributions to better understand and increase the relevance of chemistry education – both from a theoretical and practical perspective.

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ONNO DE JONG AND VICENTE TALANQUER

2. WHY IS IT RELEVANT TO LEARN THE BIG IDEAS IN CHEMISTRY AT SCHOOL?

Many students are not very interested in the content of school chemistry lessons. They wonder why they need to know the chemistry concepts. In this contribution, their question is reformulated in broader terms as illustrated by this chapter's title and different answers are explored from the perspective of two important groups of stakeholders in chemistry education: educators and students. Our analysis reveals that common responses to our guiding question can be categorized in terms of personal/chemistry relevance, societal/chemistry relevance, and vocational/chemistry relevance. In particular, chemistry educators tend to value the teaching of foundational big ideas of chemistry with the goals of: (i) preparing students for understanding other chemistry concepts, and (ii) understanding chemistry as a particular way of examining the natural world. On the other hand, students seem more interested in learning big ideas that are directly related to their personal life. In general, educators judge conceptual big ideas of and about chemistry as more relevant than contextual big ideas of chemistry, while students are more interested in contextual issues that affect them personally. We discuss major implications of these different perspectives for improving chemistry education.

INTRODUCTION

> *The blast furnace, so when are you going to use a blast furnace? I mean, why do you need to know about it?* Student aged 16 (Osborne & Collins, 2001, p. 449)

Science in general and chemistry in particular are important parts of our intellectual and cultural heritage because they provide very valuable descriptions, explanations, and predictions regarding the natural world. However, answers to the questions of what to teach in secondary schools and why to teach it have been the subject of debate for many years. The search for these answers has led to several educational reforms over the past fifty years (DeBoer, 2014). Questions about the relevance of what is to be taught in schools have always been present in educational reform discussions. For example, what content is relevant to teach? For what purpose should this content be taught? For whom should the content be relevant? The responses to these questions often vary among different stakeholders in science education. The goals of policy makers are not always aligned with those of educators, and what they value is often different from what students' judge

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relevant to them. In fact, many students do not find the content of science education courses very interesting and are thus not motivated to invest too much effort in these classes (Osborne & Collins, 2001).

Various authors have analyzed different meanings that the concept of ‘relevance’ may have in science education (Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013) as well as different approaches to identifying relevant science content to be taught in secondary schools (Hofstein, Eilks, & Bybee, 2011). It is our goal in this chapter to analyze and discuss the views of chemistry educators and students of chemistry about what big ideas in the discipline should be addressed in the classroom and for what purposes. Better understanding how educators and students think about these issues can help us devise strategies not only to challenge their perceptions when needed but to better align the goals of the different stakeholders involved in the design and implementation of chemistry curricula.

Given our interest in exploring and analyzing educators’ and students’ views about the relevance of big ideas in chemistry, we begin this chapter by summarizing important points about the relevance of education, and of chemistry education in particular, to individuals and societies. Then we discuss how big ideas have been traditionally conceptualized in chemistry education and their relationship to different curricular perspectives. The core of the chapter focuses on describing and analyzing existing findings about chemistry educators’ and students’ views about what big ideas should be taught in secondary school classrooms and why it is relevant to learn them. We close our contribution by providing some reflections about how to create conditions and learning environments in which different types of big ideas and various domains of relevance can be symbiotically integrated.

RELEVANCE OF CHEMISTRY EDUCATION

The term ‘relevance’ can have a variety of conceptual meanings. These meanings overlap with several other psychological concepts, such as interest, meaningfulness, and worth. This overlap has been extensively discussed by Stuckey et al. (2013) and will not be addressed here. We will discuss, however, how relevance is often characterized in educational fields, with a particular emphasis in chemistry education.

Relevance of education

Many centuries ago, young people got their education at home and in streets, fields, market places, and craft factories. With the increase in population and the development of more complex societies, a significant part of people’s education became the responsibility of schools. Nowadays, formal education in schools plays an important role in many countries and serves many goals. Well-known descriptions of these educational goals are often inspired by the ideas of the famous German scholar Wilhelm von Humboldt (1767-1835) and the influential French sociologist Émile Durkheim (1858-1917). The former scholar coined the educational goal of "Bildung", a term that has no precise equivalent in English and is often translated as 'personal growth' or 'self-cultivation' (Bruford, 1975). Durkheim on the other hand conceptualized the educational goals of 'socialization' and 'qualification' (Lukes, 1973). These three main goals of education can be summarized in general terms as follows:

- The goal of personal growth ('Bildung'), directed at stimulating students to shape their individual identity through growing experiences in the cognitive, affective, and psychomotor domains.
- The goal of socialization, focused on preparing students to become responsible citizens through learning of social rules, accepting social roles, and acquiring skills that are required for fruitful interactions with other people in society.
- The goal of qualification, directed at preparing students for employment in fields that best suit their interests, ambition, and abilities.

These goals represent specific domains of relevance of education which are often indicated as: (i) domain of personal relevance, (ii) domain of societal relevance, and (iii) domain of vocational relevance (Stuckey et al., 2013). The goals and domains of relevance need to be elaborated for each of the subject disciplines in schools. For chemistry, this is done below.

Relevance of chemistry education

Major goals for science education have been outlined in educational policy documents across the world, such as the USA Benchmarks of Science Literacy (AAAS, 1993) and the USA National Science Education Standards (NRC, 1996). In particular, DeBoer (2000) presented a list of nine core goals for science education that can be used as a guide to characterize goals in chemistry education as well. These goals can be related to the three domains of relevance described above:

- Domain of *personal/chemistry relevance*. This domain encapsulates the aspiration that all students will "*experience the richness and excitement of knowing about and understanding the natural world; [and] use appropriate scientific processes and perspectives in making personal decisions*" (NRC, 1996, p. 13). More specifically, within this domain it is expected that chemistry education will enable students to: (i) consider chemistry as a particular way of examining the natural world, (ii) experience the interesting relationship between chemistry and technology because it deals with concrete objects from their everyday life, (iii) understand the applications of chemistry in their daily life, and (iv) value aesthetic aspects of chemistry phenomena for personal satisfaction (DeBoer, 2000).
- Domain of *societal/chemistry relevance*. This domain encapsulates the aspiration that all students will "*engage intelligently in public discourse and debate about matters of scientific and technological concern*" (NRC, 1996, p. 13). More specifically, within this domain it is expected that chemistry

education will enable students to: (i) understand the (historical) influence of chemistry on society, (ii) be informed citizens who are prepared to deal with chemistry-related societal issues, to vote responsibly, and to influence, when appropriate, policies related to the impact of chemistry on society, (iii) critically follow discussions about chemistry in the popular media, and (iv) be citizens who have a positive attitude toward chemistry (DeBoer, 2000).

- Domain of *vocational/chemistry relevance*. This domain encapsulates the aspiration that all students will "*increase their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers*" (NRC, 1996, p. 13). More specifically, within this domain it is expected that chemistry education will enable students to be aware of opportunities for further study and chemistry-related careers (DeBoer, 2000).

It should be pointed out that these three domains of relevance, and their associated goals, overlap to varying degrees and are thus not mutually exclusive. To a great extent, these three domains capture the perspectives of various stakeholders, including policy makers, scientists, educators and students, about the relevance of chemistry education. These groups, however, may differ in the degree to which they value each of the different relevance domains and their associated goals. How relevance is represented in chemistry curricula is thus the result of negotiations between diverse groups. For many years, the most influential stakeholders were the associations of chemists who often thought of secondary school chemistry education as the first step towards further studies in the discipline rather than as relevant education for all. But perspectives in this area are changing, mainly because of a broad public debate in many countries about the goals of education in general and of chemistry education in particular. These types of debates affect people's beliefs about what "big ideas" should be taught in schools and for what purpose.

BIG IDEAS IN CHEMISTRY EDUCATION

The term 'big ideas' can have a variety of meanings which depend on the context in which the term is used and on the level of specification. For instance, 'salt' can be considered as a big idea in inorganic chemistry but can also be seen as part of the overarching big idea of 'substance' in general chemistry.

Function and categories of big ideas

Big ideas in chemistry are useful because they provide frameworks comprised of interrelated concepts, rules, and methods (cf. Fensham, 1975). A term that is similar to 'big idea' was introduced by Erduran and Scerri (2002) who coined the term 'class concepts'. These authors pointed out that class concepts function as important means of representations of chemistry entities. Examples of class concepts are 'acid', and 'element'. Class concepts can support chemists in the investigation and classification of substances and reactions, as well as of submicroscopic particles and their interactions.

In chemistry education, big ideas can be very helpful in discussions about the aim and core content of chemistry curricula. These discussions can focus on the clarification of relevant big ideas and their elaboration in terms of related specific chemistry concepts for teaching and learning. In this chapter, two main categories of big ideas are distinguished. On the one hand we can identify "contextual" big ideas in the discipline that refer to chemical understandings that are directly relevant to individuals and societies. These types of ideas can be general or specific, although a sharp distinction between these subcategories cannot be made. Particular examples of these different types of big ideas are presented in Table 1. On the other hand, we can highlight "conceptual" big ideas which include big ideas *of* chemistry and big ideas *about* chemistry as illustrated in Table 1. These types of ideas encapsulate, respectively, fundamental chemical understandings about the structure of matter and its properties, and about the nature and practice of chemistry. Contextual ideas and conceptual ideas are related to each other in various ways. For example, a particular contextual idea can encompass several different conceptual ideas while a specific conceptual idea may support the understanding of several contextual ideas. In this chapter, the expression 'big ideas *in* chemistry' often refers to a combination of the different categories of ideas summarized in Table 1.

Table 1. Categories of big ideas in chemistry with examples

Category of big ideas in chemistry	Example of a big idea
Contextual big idea	
· General	· Chemistry for sustainability
· Specific	· Ozone layer chemistry and effects
Conceptual big idea	
· Of chemistry	· Bonding; chemical equilibrium
· About chemistry	· Nature and methods of chemistry

Some sets of big ideas from half a century ago

About half a century ago, in 1957, chemistry education got a boost through the launching of the first artificial earth satellite (the 'Sputnik') by the Soviet Union. This happened in the middle of the Cold War era and it caused a shock around the world because it exposed the relative weakness in science and technology of western industrialized countries, especially the USA. Experts considered that one of the main causes of the perceived deficit was the relative low quality of existing science and technology curricula. They characterized such curricula as old-fashioned, overloaded, and mainly consisting of unrelated concepts without reference to big ideas as organizing frameworks. Although this criticism was not new, the 'Sputnik' effect made policy makers in the western world more willing to pay attention to it and stimulated the development of a wave of new chemistry curricula.

In the 1960s, chemistry curriculum reform in the USA was supervised by the American Chemical Society (ACS) as the main stakeholder. This organization guided the development of two large-scale projects for secondary schools, first the *Chemical Bond Approach* (CBA) project (Strong, 1964), and later on the *Chemical Education Material Study* (CHEMStudy) project (Pimentel, 1963). Both curricular projects focused on reducing the total number of isolated concepts and introducing big ideas in chemistry for stimulating understanding. For instance, the CHEMStudy textbook did not longer include traditional concepts as equivalent weight, molality, normality, and electrovalence, and organized the chemistry content into the following main division of topics (Merrill & Ridgway, 1969):

- The particulate nature of matter
- Atomic structure and the Periodic Table
- Molecules; chemical bonds
- Reactions; stoichiometry; equilibrium; energetic; rates
- Systematic descriptive chemistry

In the same decade, chemistry curriculum reform in the UK was directed by the Nuffield Foundation as the main stakeholder. This organization supported the development of the large-scale 'Nuffield Chemistry' project for secondary schools (Halliwell, 1966). This project targeted the following big ideas:

- The Periodic Table of elements (organizer of properties of substances).
- Structure-property relationship (organizer of links between core characteristics of submicroscopic particles and macroscopic phenomena).
- Energy change (organizer of explanations for the occurrence of chemical reaction).

Some sets of big ideas from more recent years

In the 1980s, a second wave of chemistry curriculum reform was initiated in several western countries, mainly because of the alarming USA report 'A Nation at Risk' (NCEE, 1983). This report highlighted the poor performance of American youth in mathematics and science and spearheaded the development of large-scale curricular reform projects such as *Chemistry in the Community* (ChemCom) (ACS, 1988), sponsored by the ACS, and the UK project *Chemistry: The Salters Approach* (UYSEG, 1989), sponsored by the Salters' Institute of Industrial Chemistry. In these secondary school reform projects, chemistry concepts were introduced as needed to understand relevant situations in personal life or societal events. Moreover, issues concerning the relationship between chemistry, technology and society were introduced. For instance, the Salters project designed teaching/learning units in which contextual big ideas were related to conceptual big ideas, such as:

- 'Buildings' unit including reactions of building materials with acids, factors that affect the rate of these reactions, and other topics,

- ‘Fighting disease’ unit including chemical reactions inside our body, properties of enzymes, structure and activity of effective medical drugs, and other topics.

In the 1990s and 2000s, several other large-scale projects for secondary schools applied the approach of context-led development of chemistry concepts, such as the UK project *Salters Advanced Chemistry* (SAC project, 1994), the German project *Chemie im Kontext* (Gräsel, Nentwig, & Parchmann, 2005) and the Dutch national curriculum project *New Chemistry* (Apotheker et al., 2010). For instance, in the latter project several context-based chemistry modules were designed, such as (De Jong, 2015):

- ‘Eco-travelling’ module including introductory organic chemistry, mole, molar mass, stoichiometric calculations, and other topics,
- ‘Plants from the earth’ module including electrolytes, precipitation reactions, calculations on solutions, and other topics.

Recent discussions about sets of big ideas

The reform movement since the 1980s shifted the curricular focus from conceptual big ideas toward contextual big ideas. Nevertheless, conceptual big ideas remained central in discussions about curricular matters in chemistry education at all educational levels (Talanquer, 2013). This perspective was emphasized, for example, by Gillespie (1997), one of the main developers of the famous VSEPR theory in chemistry, in his article “The great ideas of chemistry” where he proposed the following set of fundamental ideas for learning:

- Atoms, molecules, and ions
- The chemical reaction
- The chemical bond
- Molecular shape and geometry
- The kinetic theory
- Energy and entropy

According to Gillespie, these big ideas can function as the curricular bottom line and be expanded with more specific chemistry concepts. Although the presented list was proposed for learning in college general chemistry courses in the USA, this set of big ideas is commonly found in traditional secondary school chemistry curricula in many countries.

Big ideas in chemistry are commonly expressed around core concepts in the discipline, such as ‘atom’, ‘chemical bond’, and ‘chemical reaction’. They tend to represent fundamental knowledge that chemists have about the properties and behavior of matter. Recently, Sevian and Talanquer (2014) introduced a different approach to characterizing big ideas in chemistry. They identified a set of crosscutting concepts judged to be critical in the understanding and practice of chemistry. As shown below, each of these concepts is associated with a core question driving chemical thinking. These big ideas highlight the underlying goals of the chemical enterprise (e.g., analysis, synthesis, transformation) and provide a framework for building connections between core chemistry concepts (e.g., element and compound, bonding, chemical equilibrium) and their application in the understanding of relevant problems (Talanquer & Pollard, 2010). The big ideas of these scholars can be summarized as follows:

- Chemical identity (How do we identify chemical substances?)
- Structure-property relationship (How do we predict properties of substances?)
- Chemical causality (Why do chemical processes occur?)
- Chemical mechanism (How do chemical processes occur?)
- Chemical control (How do we control chemical processes?)
- Benefits-costs-risks (How do we evaluate impacts of chemical processes?)

Big ideas and chemistry curricular perspectives

The introduction and elaboration of big ideas in the chemistry classroom is always guided and constrained by a set of curricular perspectives. These perspectives can be defined as coherent sets of messages to students about chemistry, rather than within chemistry (cf. Roberts, 1982). This meaning was applied by Van Berkel, De Vos and Verdonk (2000) to the identification of three main curricular perspectives guiding existing chemistry curricula (see also the chapter by Sevian and Bulte in this book). Each of these perspectives (renamed by Van Driel, Bulte, & Verloop, 2005) can be characterized by a dominant conception about chemistry. A concise overview is given below.

- 'Fundamental Chemistry' (FC) perspective. The dominant characteristic is the conception that chemistry is a conceptual and cumulative scientific system. The curricular focus is mainly on learning to describe, explain, and predict chemistry phenomena.
- 'Knowledge Development in Chemistry' (KDC) perspective. The dominant characteristic is the conception of chemistry as a scientific system that continuously develops through the active participation of chemists. The curricular focus is mainly on learning how knowledge in chemistry is developed in socio-historical settings.
- 'Chemistry, Technology, and Society' (CTS) perspective. The dominant characteristic is the conception that chemistry is a scientific system that plays an important role in technology and everyday life at the personal and societal level. The curricular focus is mainly on learning chemistry concepts and processes that are relevant to understanding socio-scientific issues and contexts.

These curricular perspectives act both as filters and frames for the big ideas that are highlighted in the chemistry classroom. For instance, the FC perspective will include conceptual big ideas *of* chemistry such as particulate nature of matter, chemical reaction, chemical bonding, and reaction energy. In a KDC perspective more emphasis will be placed on the conceptual big ideas *about* chemistry such as the role of experiments in the chemistry lab, the function of chemistry models, and the shift of paradigms in chemistry. Finally, the CTS perspective will include contextual big ideas such as greenhouse mechanisms, substance toxicity, and chemical pollution.

Different views about chemistry and about chemistry education are likely to influence peoples' beliefs about which big ideas are relevant to learn at the secondary school level. In the following sections, we summarize important results related to the perceptions of relevance of learning big ideas in chemistry held by educators and students.

EDUCATORS' VIEWS OF BIG IDEAS RELEVANT TO LEARN

Studies on the views of educators about what big ideas to emphasize at the secondary school level and the reasons to do so are scarce. The results of an interesting study in this area were reported by Van Driel, Bulte, and Verloop (2005) who collected answers to a questionnaire focused on teachers' content-related views about the chemistry curriculum as well as their general educational beliefs. The content-related views were investigated by including statements about the FC, KDC, and CTS perspectives given above. The general educational beliefs were investigated by including statements about discipline-oriented beliefs and learner-centred beliefs. The respondents were asked to indicate their (dis)agreement with different statements using a 5-point Likert scale. The questionnaire was mailed to nearly all chemistry teachers in The Netherlands, with a response rate of 36% (348 teachers).

Van Driel et al.'s (2005) study showed that all curricula perspectives were valued positively by teachers (mean score 3.5-4.0). The FC curriculum perspective got the strongest support (mean score 3.9). The CTS perspective scored statistically significant lower (mean score 3.8), just as the KDC perspective (mean score 3.6). These findings indicated the dominant influence on teachers' beliefs of current chemistry curricula which strongly focus on teaching and learning conceptual big ideas *of* chemistry. Nevertheless, the teachers considered important to also pay attention, although to a lesser extent, to contextual big ideas and to conceptual big ideas *about* chemistry. The authors of this study also tried to identify relationships between teachers' curricular views and their general educational beliefs. In particular, they found two major connections: (i) the FC perspective and a discipline-oriented belief, and (ii) the CTS perspective and a student-centred belief. The KDC perspective could not be assigned exclusively to one of these combinations.

The above study did not provide information about what specific big ideas are relevant to learn at school, and for what specific purposes. To gain more insight into these issues, the first author of this chapter conducted a small-scale exploratory study that revealed a range of opinions in this area. This study is concisely reported below.

Method and participants of the explorative study

The study was based on a short self-completion questionnaire. The respondents of the questionnaire were participants of the 12th European Conference on Research in

Chemistry Education in Jyväskylä, Finland, July 2014. For that reason, they were considered as experts in the field of chemistry education.

The written survey consisted of two main parts. The first part (about big ideas relevant to learn) is presented here; the second part (about reasons for this relevance) is addressed in the next section. The survey was distributed among conference participants who cooperated voluntarily. As part of the survey, participants were asked to state their profession by answering a multiple-choice question. A total of 54 completed questionnaires were collected at the end of the event. Nearly half of the respondents indicated to have more than one profession. When this overlap in profession was taken into account, the percentage of categories of professional expertise of the respondents in the group was as follows: 65% chemistry education researchers, 50% chemistry teachers, 46% chemistry teacher educators, and 17% chemistry curriculum developers.

The first main question in the survey was expressed in the following manner: *What are the big ideas in chemistry that are relevant to learn at secondary schools?*

The answers to the question were analyzed by a step-by-step procedure. In the first step, the answers were classified by using a set of main analysis categories consisting of the categories of Sevian and Talanquer (2014) (as described in the previous section) and the well-known categories of 'nature of chemistry' and 'methods of chemistry'. In the second step, the statements attributed to each category were clustered into subcategories based on their common content. In the final step, the main categories were clustered under the heading of the three curricular perspectives reported by Van Driel et al. (2005) (see previous section). The analysis was carried out by the authors, both experts in chemistry education, and included an iterative cyclic process in which an initial analysis was followed by another set of analyses at a later time. A comparison of the results delivered the findings that are presented below.

Reported big ideas relevant to learn

Major findings about chemistry educators' views of big ideas relevant to learn are summarized in Table 2. The table only incorporates big ideas that were reported by at least 10% of the educators. As mentioned before, the ideas have been arranged using curricular perspectives and crosscutting concepts as organizing frameworks.

If we analyze the frequency with which different big ideas were reported by the surveyed chemistry educators, our results suggest a strong preference for conceptual big ideas *of* chemistry classified within a FC curricular perspective (78.2% of instances presented in Table 2). Within this group, over three quarters of those instances corresponded to big ideas related to chemical identity and structure-property relationship. Big ideas in the areas of chemical causality, mechanism, and control were mentioned to a lesser extent. Preference for conceptual ideas *about* chemistry categorized within a KDC curricular perspective in Table 2 was much lower, with only 13.4% of all instances in this group. The least emphasized category corresponded to contextual big ideas of chemistry related to benefits-costs-risks within a CTS curricular perspective, with only two big ideas mentioned in this area and a mere 8.4% of total instances.

Our results confirm chemistry educators' preference for conceptual big ideas *of* chemistry over both conceptual big ideas *about* the discipline and contextual big ideas related to personal and societal issues. This lack of attention to CTS issues was also reported by Aikenhead (2006) who showed that teachers often tend to teach chemistry topics without much contextual connotations.

Table 2. Chemistry educators' views of big ideas relevant to learn

Curricular perspective and related category of big idea	Big idea relevant to learn*	Frequency of big idea (54 educators)
(*FC curricular perspective*)		
Chemical identity	Particulate to nature of matter	21
	Chemical reaction	19
	Chemistry products in everyday life	12
	Substance	8
	Quantitative chemistry	6
Structure-property relationship	Structure-property relations	20
	Bonding	17
Chemical causality	Reaction energy	14
Chemical mechanism	Mechanism for interaction	6
Chemical control	Chemical equilibrium	10
	Chemical kinetics	7
(*KDC curricular perspective*)		
Nature of chemistry	Models	6
	Chemical "language"	5
Methods	Techniques of chemistry and chemists	7
	Experiments	6
(*CTS curricular perspective*)		
Benefits-costs-risks	Impact of chemistry	10
	Environmental chemistry	5

* Only big ideas that were reported by at least 10% of the educators are incorporated

EDUCATORS' VIEWS OF WHY THE BIG IDEAS ARE RELEVANT

Our survey also explored chemistry educators' beliefs about the relevance of learning the big ideas that they selected. In particular, survey participants were asked to answer the following question: *Why is the learning of the big ideas relevant?*

The answers of the 54 chemistry educators in our exploratory study were analyzed by a step-by-step procedure, using analytical categories related to goals of chemistry education and domains of relevance. In particular, the specific goals of chemistry education (as described in a previous section) functioned as initial analytical categories for classifying the answers. Beside these categories, a needed extra category was used, viz. 'Preparing for understanding follow-up chemistry concepts'. In a second step, the classified answers were clustered under the headings of the three chemistry-specific domains of relevance.

Reported reasons for relevance of the big ideas

Major findings about chemistry educators' beliefs about the relevance of learning the big ideas in chemistry are summarized in Table 3. This table only includes results for categories that capture the beliefs expressed by more than 10% of the educators.

Table 3. Chemistry educators' views of reasons for relevance of the big ideas

Domain of relevance and related category of reason for relevance	Frequency of reason (54 educators)	Example of a statement
(*Personal/chemistry relevance*)		
Preparation for understanding follow-up chemistry concepts	21	"To explain reactivity and how to obtain new structures, and how to control reactions"
Considering chemistry as a particular way of examining the natural world	17	"If you want to understand the material world that we live in (...), the basic concepts of the chemistry are relevant and helpful"
Understanding the applications of chemistry in students' daily lives	14	"Be able to understand chemi-cal phenomena as cooking, rusting"
(*Societal/chemistry relevance*)		
Understanding the (historical) influence of chemistry on society	13	"Impacts (social, economic, environmental, etc.) of use and development of materials
Development of informed citizens dealing with chemistry-related societal issues	10	"To have a good fundament to discuss and to make own decisions and to improve the world a little better"
(*Vocational/chemistry relevance*)		
Awareness of further study and chemistry-related careers	9	"Students could confront university studies with better preparation"

Analysis of the frequency of different expressed reasons for learning big ideas in chemistry revealed a clear dominance of justifications within the personal/

chemistry category (61.9% of instances), with a strong emphasis on learning chemistry for better understanding other chemistry concepts and examining the natural world. Considerations related to societal (27.4% of instances) or vocational (10.7% of instances) relevance was much less frequent in our sample. From a further analysis it appeared that, in general, reasons expressed for learning big ideas in chemistry were not clearly correlated to the categories of big ideas presented in Table 2. This is, chemistry educators expressed a variety of reasons for learning a given big idea in Table 2, and a single category of reasons was linked to different big ideas in such table.

Overall, our results suggest that a majority of chemistry educators considered that the central goal of school chemistry was to help students understand conceptual big ideas *of* the discipline with the goals of better understanding other chemistry concepts and examining the natural world.

STUDENTS' VIEWS OF RELEVANCE OF CHEMISTRY TOPICS

The beliefs of chemistry education experts about the big ideas of chemistry and their relevance can be expected to differ from those of students. Such a comparison, however, is hard to make because investigations about students' beliefs about learning chemistry are also scarce. An important study in this area was conducted by Osborne and Collins (2001) who used a focus-group open interview method involving 144 science students aged 16. They investigated students' views of the role and value of the science curriculum in the UK. Although these authors did not directly ask students about big ideas in chemistry, their results revealed that phenomena involving observables ('smells and colours') and manipulations ('mixing chemicals') evoked the most interest among participants. Elements of danger associated with chemistry issues were also seen as interesting ('exciting'). In general, students were more engaged with science topics perceived to be of personal relevance, particularly in regards to their everyday lives.

Other studies have investigated students' views by using closed questionnaires that include a number of chemistry concepts or topics. The results of two important large-scale projects that applied such methodology are summarized below.

The ROSE project

An important study that offers insights into students' views of relevance of chemistry topics is the recent project 'Relevance of Science Education' (ROSE) (Sjøberg & Schreiner, 2010). Despite this name, the project team prefers to refer to 'student interest' in their study. Although this project focuses on the broad domain of science education, the results provide some insights into chemistry curriculum issues. The large-scale project was launched in some 40 countries and used a closed questionnaire which was completed by thousands of ~15 year old students. The questionnaire included about 108 items that asked students to rank their interest in different science topics using a 4-point Likert scale. Only 10 of these topics were directly related to chemistry.

In general, students' expressed interest in chemistry topics was low. This is illustrated in Table 4 where we present results corresponding to the ROSE scores of 3626 students in Finland, a top ranking country in international PISA and TIMSS studies (Lavonen, Byman, Uitto, Juuti, & Maisalo, 2008). It is interesting to point out that student interest scores in poor countries were somewhat higher than in wealthy countries such as Finland.

Table 4. Students' views of relevance of chemistry topics (Lavonen et al., 2008, pp. 21-23)

Chemistry topics from the ROSE project	3626 students (1 = not interested; 4 = very interested)
Deadly poisons and what they do to the human body	2.7
How different narcotics might affect the body	2.7
How alcohol and tobacco might affect the body	2.6
What can be done to ensure clean air and safe drinking water	2.6
Biological and chemical weapons and what they do to the human body	2.5
Explosive chemicals	2.4
The greenhouse effect and how it may be changed by humans	2.2
The ozone layer and how it may be affected by humans	2.2
Chemicals, their properties and how they react	2.0
Detergents, soaps and how they work	1.9

The results in Table 4 indicate that students' interest was relatively higher for topics that may affect them at the personal level, in alignment with Osborne and Collins (2001) results. These findings suggest that students' views on relevance tend to align with the personal/chemistry relevance domain. However, the ROSE questionnaire also included 16 items that could be linked to the two other domains: societal/science relevance and vocational/science relevance. Examples of these items were: "*School science has shown me the importance of science for our way of living*" and "*I think that the science I learn at school will improve my career chances*" (Sjøberg & Schreiner, 2010, p.13). Students' scores for these items varied strongly between countries, but students from Europe and Japan ranked the social relevance as well as the professional relevance of science education lower than students from other countries.

The Swedish project

Another interesting project, not related to ROSE, focused on students' views of chemistry topics only (Broman, Ekborg, & Johnels, 2011). In this study, 372

Swedish school students (aged 18-19 years) completed a questionnaire that included a list of 10 chemistry topics. From this set, the students were asked to mark the three topics that were most relevant and the three topics that were least relevant to them. The results of this study are summarized in Table 5, where we can see that those topics more closely related to personal matters (e.g., biochemistry) were the most preferred. These findings reinforce the suggestion that students' interests are closely aligned with the goals of the personal/chemistry relevance domain.

Table 5. Students' views of relevance of chemistry topics (Broman et al., 2011, p. 47)

Chemistry topic from the Swedish project	Relevance for 372 students	
	Most	Least
Biochemistry	56%	18%
Organic chemistry	46%	19%
Atomic structure	36%	23%
Acids & bases	30%	16%
Chemical analysis	26%	33%
Chemical calculations & stoichiometry	23%	34%
Chemical bonding	20%	32%
Energy/enthalpy	18%	44%
Oxidation & reduction	18%	32%
Chemical equilibrium	17%	37%

Looking back at both studies on students' views of relevance

Results from the ROSE study showed that four out of ten chemistry topics had a relevance score higher than 2.5 which is the score of neutral perceived relevance. The four topics at the top of the rankings: poisons, drugs, clean air, and safe drinking water can be situated in the context of health issues. These top scores are in line with the results of the Swedish study which reported that top perceived relevance was attributed to biochemistry and organic chemistry, two areas closely related to the four top ROSE chemistry topics. Results from this latter project also indicated that environmental topics that may have not been perceived as directly related to personal life (greenhouse effect, ozone layer) received a lower relevance score.

Major findings from the two studies described in this section suggest that students' views of relevance seem to be strongly aligned with goals in the personal/chemistry relevance domain. Interest in other contextual topics, such as safety and environment, which may be placed in the societal/chemistry relevance domain, tends to be lower. Students often consider the study of personally relevant contexts involving chemistry topics as more interesting than the study of foundational chemistry topics. These types of preference have also been found in other disciplines. For instance, Häussler and Hoffmann (2000) showed that the context 'the rainbow and sunsets' is viewed as much more relevant than the topics 'light and optics' in the area of physics. In general, students often attribute a higher relevance to contextual big ideas than to conceptual big ideas.

Finally, the ROSE study revealed that, in general, students' judgments of relevance can differ between boys and girls and between students from countries with different socio-economic conditions (Schreiner & Sjøberg, 2007).

CONCLUSION

This chapter revealed a number of answers to the guiding central questions: "What are the big ideas in chemistry that are relevant to learn in secondary school?", and, "Why is it relevant to learn such big ideas?". The answers to these questions came from two important groups of stakeholders in chemistry education: educators and students. Core answers were categorized in different groups based on the types of ideas selected and the domains of relevance to which they seemed to belong.

Our study of chemistry educators' views indicated that they had a preference for teaching the conceptual big ideas *of* chemistry, with an emphasis on chemical identity and structure-property relationship concepts. The educators gave reasons for learning the presented big ideas that fell within two main categories in the domain of personal/chemistry relevance, viz. (i) preparation for understanding follow-up chemistry concepts, and (ii) considering chemistry as a particular way of examining the natural world. On the other hand, investigations about students' interests suggested that students' preferences also fell within the personal/chemistry relevance domain, but with an emphasis on everyday personal matters. Students tended to be more interested in learning contextual big ideas in the discipline than foundational concepts. The societal and vocational relevance of chemistry seemed to be secondary for these two groups of stakeholders.

The similarities and differences between chemistry educators' and students' views about big ideas and their relevance has important implications for teacher education and the development of chemistry curricula. Many courses for pre/in-service teacher preparation usually focus on the description of students' difficulties understanding foundational chemistry concepts, without much discussion of the relevance of such concepts in different domains or much analysis of how to help students apply such concepts to answer relevant questions at the personal, societal, and vocational levels. As Aikenhead (2006) indicated, educators are inclined to marginalize student-focused views of everyday life, and opportunities need to be created for teachers to critically reflect on different beliefs, including their own, those of their students and of other chemistry educators, about what is important to teach and why it is important to teach it.

These types of reflections are necessary not only to affect teachers' approaches to teaching chemistry but also their views about the chemistry curriculum. Current educational reform efforts in many countries are focused on developing chemistry curricula that aim at taking students' interest into account. Chemistry teachers are getting more involved in the early stages of curriculum development projects. This gives them the opportunity to act as co-stakeholders who participate in discussions about the selection of relevant big ideas. The contrasting views about relevance held by educators, students, chemistry experts, and policy makers should be made explicit and analyzed in these discussions. These types of reflections can lead to curricular decisions about content and sequence that are likely to increase the success of new chemistry education projects.

Relating a big idea to all three domains of relevance

Chemistry educators should face the challenge of identifying big ideas that have potential roots in all three domains of relevance described in this chapter, and can thus create rich learning opportunities that expand the conceptual and the contextual arenas (Hofstein et al., 2011). An example of such an idea is 'Water Quality' (Bulte, Westbroek, De Jong, & Pilot, 2006). This contextual big idea can be elaborated as follows. Regarding the personal/chemistry relevance, the big idea can include the teaching of the issue of safe drinking water. This topic has a strong connection to everyone's daily life and has a high relevance score among students as the previously described ROSE/Finnish study has shown. Moreover, this big idea offers opportunities for applying a number of underlying chemistry concepts such as solution, electrolyte, purification, standardization of quality analyses, and the need for accuracy of lab experiments. Regarding the societal/chemistry relevance, the idea of water quality opens the door to the discussion of issues such as the pollution of surface water and its economic and social impacts. Analysis of these problems can contribute to students' understanding of how chemistry actually functions in society and create a solid foundation for public discussions about the water pollution problem. In the domain of vocational/chemistry relevance, engagement with this big idea could expose students to potential careers such as chemical lab analyst and chemical engineer, and to reflections of their value to society.

In general, reflecting on core chemistry practices, such as chemical analysis, synthesis, and transformation, and underlying central activities, such as investigation, design, and evaluation (Sevian & Talanquer, 2014), can help chemistry educators identify big ideas that are embedded in all three domains of relevance and target conceptual and contextual concepts. From analysis of water quality to synthesis of renewable materials to transformation of waste, chemistry curricula can be designed to help students understand how to use foundational concepts to answer questions and make decisions in areas of relevance to people and to the societies they live in.

Bringing conceptual and contextual big ideas in good balance

Gilbert, De Jong, Justi, Treagust, and Van Driel (2002) have emphasized the importance of identifying where the big ideas in chemistry are likely to be encountered out-of-school. This suggestion is in line with the view expressed by Westbroek, Bulte, and Pilot (2001) that not all traditional big ideas in chemistry education need to be part of a 'chemistry toolbox' of core student competencies. According to these scholars, selected big ideas must be functional for adopting a chemical perspective when dealing with societal issues. These big ideas must then be derived from the analysis of representative socio-scientific and events. De Vos, Bulte, and Pilot (2002) gave an example for the traditional case of learning about the production of ammonia. They argued that this production is very useful in society, e.g. production of fertilizers, and, for that reason, the concepts that are related to methods for optimizing the yield of ammonia, such as selecting an appropriate pressure and catalyst, should be considered as bigger ideas than the concept of the equilibrium constant which is usually emphasized in traditional chemistry curricula.

Although the perspective of deriving big ideas from meaningful societal issues is attractive, this practice can be problematic if the ideas selected are too narrow in scope and are only relevant to specific societal issues. Similarly, too much of a focus on acquiring specialized chemistry knowledge for the sake of creating a solid foundational base has proved to be ineffective in fostering meaningful understandings and motivation to learn. A more productive approach should strive for a well-balanced symbiotic relationship between conceptual big ideas of chemistry and contextual big ideas about socio-scientific issues. Our chemistry students will become citizens who will 'consume' information involving chemistry issues, such as the controversial impact of diverse chemicals on human health and the environment. To be able to effectively contribute to the public debate on these issues, students need to not only understand the specific socio-scientific problems under consideration but also acquire a broad understanding of core big ideas *of* chemistry and of big ideas *about* chemistry. These latter understandings are needed for students to recognize the scope and limitations of chemistry knowledge and research, learn to discriminate between data and beliefs, and adopt a critical perspective when confronted with debates that involve chemistry related issues (e.g., use of fracking technology to extract fossil fuels, control of greenhouse gas emissions; see also the chapter by Sjöström et al. in this book).

Enhancing the three domains of relevance

The relevance of big ideas of chemistry and about chemistry in the three major domains described in this chapter can be enhanced by introducing a number of educational measures:

- Personal/chemistry relevance of big ideas can be enhanced by promoting open-inquiry activities and problem-based learning in the classroom focused on students' interest. These approaches demand a change in the role of teachers from transmitters of chemistry content towards facilitators of self-directed student learning.
- Societal/chemistry relevance of big ideas can be enhanced by teaching chemistry in contexts. This can be accomplished by developing and implementing context-based modules about socio-scientific issues involving chemistry topics.
- Vocational/chemistry relevance of big ideas can be enhanced by organizing contacts between schools, chemistry faculty at universities, and chemical

industries. This can be done by stimulating visits from students to chemistry labs at university/industry, and inviting professional chemists as guest-teachers at school.

The extent to which these types of measures have been introduced in schools varies across the world, but the presence of context-based teaching has grown considerably in recent years. This educational perspective plays an important role in several modern large-scale projects for secondary schools, such as the German project *Chemie im Kontext* (Gräsel et al., 2005) and the Dutch project *New Chemistry* (Apotheker et al., 2010). In both projects, context-based modules have been designed and field tested by chemistry teachers in a cyclic process. Using a bottom-up approach, teachers as well as their students have contributed to efforts to make big ideas in chemistry more relevant through a careful balance between contexts and concepts that are interesting to teachers and their students. In both projects, the first part of many modules contains an introductory context for evoking a 'need-to-know', the middle part focuses on findings answers involving chemistry concepts, and the final part contains a closing context for evoking a 'need-to-apply' among students (De Jong & Taber, 2014).

Existing research indicates that context-based approaches increase student interest and foster positive attitudes toward chemistry, while leading to levels of understanding of chemistry that are similar to that of conventional approaches (Bennett, Lubben, & Hogarth, 2007; Pedretti & Nazir, 2011). These results underscore the importance of striving to find an effective balance between contextual big ideas and conceptual big ideas in the design and implementation of chemistry curricula.

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3. CHEMISTRY AND EVERYDAY LIFE: RELATING SECONDARY SCHOOL CHEMISTRY TO THE CURRENT AND FUTURE LIVES OF STUDENTS

Chemistry education in secondary school is often seen as divorced from real life. It takes place in a school classroom or laboratory setting, using abstract concepts and unfamiliar language. Consequently many students do not see the relevance, interest or importance of what they study in school for their everyday life outside school or for their future role in society. However, an understanding of basic chemical and scientific ideas is more important than ever today for living in a technological society and for understanding and dealing with the problems and issues of everyday life: health, energy, environment, diet etc. Chemical literacy is needed to understand, evaluate and make decisions about many current and future issues, e.g. nuclear power, GM foods, climate change etc. Chemical education at school needs both to help students understand and use basic chemical concepts but also to relate these concepts to real-world issues and show how chemistry helps in understanding and dealing with the many science-related issues that arise in everyday life. This will provide them with the foundation for life-long learning and the ability to deal intelligently with issues in the future. The importance of chemical literacy for the citizen will be illustrated by mapping the secondary level chemistry curriculum onto current societal issues, which impinge on the everyday lives of students. Several of these topics will be described as case studies to show how the chemical ideas studied at school are useful in understanding contemporary issues. This will demonstrate how the chemistry taught in schools can equip a student to meet the challenges of an increasingly complex and science-dependent world.

INTRODUCTION

In 1985 the Association for Science Education (ASE) in the U.K. published a blueprint for *Education through Science* (ASE, 1985) where they pointed out that science education should have "*relevance: science education should draw extensively on the everyday experience of pupils*." In 1986 we ran a conference for Irish chemistry teachers on 'Everyday Chemistry' (Childs, 1986).

This was at the start of the movement in the U.K. to introduce context-based science curricula, with a focus on everyday applications of science. The main speaker, Francesca Garforth, said in her talk on 'Chemistry through the looking

I. Eilks & A. Hofstein (Eds.), Relevant Chemistry Education – From Theory to Practice, 33–54.

glass': "*Few courses draw on the experiences that pupils bring from their everyday lives and this is much more true of chemistry than the other two sciences*" (Garforth, 1986). The 1980s were the era of new context-based courses which started from the needs and interests of the students, rather than the needs and interests of university scientists. This involved turning the curriculum process around, so that it started from the students' experiences and interests and developed the appropriate science, rather than the traditional curriculum development process, which started (and still does in many countries) from the subject content and often finished there. These two approaches are contrasted in Figure 1.

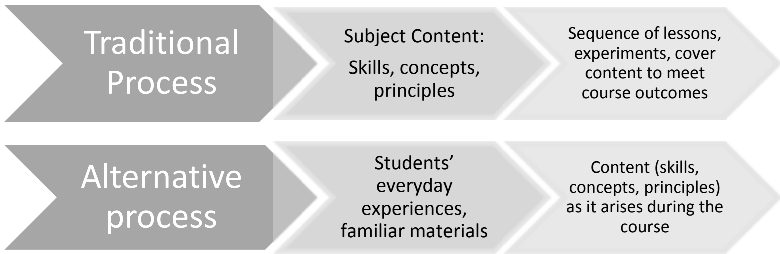

Figure 1. Two curriculum approaches in science

In this chapter we want to explore the idea of what constitutes 'everyday chemistry' and how it relates to the chemistry content of secondary level courses. Too often the way students are introduced to chemistry puts them off the subject for life: they meet abstract and difficult concepts almost in their first class (atoms, molecules, electronic structure); they are warned about the dangers of chemistry and the importance of safety when they enter the laboratory; they are expected to use strange apparatus with difficult and unfamiliar names (burette, flask, pipette); they use chemicals with unfamiliar names, which are impossible to spell; they are bombarded with a new language; and the meet arcane symbols and terminology. This strangeness and lack of connection to real life is greater for chemistry than it is for biology and physics, where students have more immediate and obvious contact with the subject matter. Chemistry teachers often enhance this strangeness by the way they introduce chemistry, without any reference to the everyday lives of their students or the real world relevance of chemistry. We could say that chemists are their own worst enemy in the way they present their subject. Research has shown that we should start with the familiar and move to the unknown; start with the concrete and move to the abstract; start simple and build up the complexity. Often chemistry teachers, following a traditional course and text book, do the exact opposite to this and we wonder why students are put off and turned off.

Jevons (1969) said this many years ago, in his book *The teaching of science: education, science and society*:

> If the paramount place is given to the interests of the students, then the educator must keep at the forefront of his mind that he is teaching students rather than subjects, and for their own sakes first and those of their future

> employers second. He has to think not how much of the subject he can get through, or how far he can meet the wishes of employers, but what and how much his students should be given so as to do them most good. (p. 139)

The idea of relating science education to the everyday lives of students is not new and in the 19th century there was a movement to teach the science of common things in elementary schools in England, associated with the name of Richard Dawes. This early but stillborn example of everyday science has been described by David Layton (1973) in his book *Science for the People:*

> Here was no crumb of upper-class education charitably dispensed to the children of the labouring poor. Instruction was related to a culture which was familiar to them and proved opportunities for the use of reason and speculation by drawing upon observations which pertained to everyday life. Understanding and the exercise of thought were not prerogatives of the middle and upper classes. (p. 53)

What was taught sounds a lot like modern context-based curricula, as this example from Dawes' teaching scheme shows:

> The materials used in building and furnishing their houses, whence obtained and how prepared. Their clothing and its materials, which vegetable, which animal; the comparative value and suitableness of different materials for different purposes, specimens of each being shown. Articles of food, whence obtained, how prepared; their dietetic properties and values; the history of a cottage-loaf. (quoted in Moore, 1904, p. 259)

Changes of personnel led to this innovative way of teaching science being dropped, which was fully integrated into the rest of the elementary curriculum, in favour of a more academic, pure science.

WHAT IS EVERYDAY CHEMISTRY?

This is sometimes called real world chemistry (Hosteller, 1983) or authentic chemistry/science (Bulte, Westbroek, De Jong, & Pilot, 2006; Lombardi, 2007), although authentic contexts can mean either everyday contexts or professional scientific contexts.

There are different ways of relating everyday chemistry to the school curriculum and to the interests of secondary students. We could consider, for example, materials that are used every day, or the chemistry of everyday objects, or that of everyday activities students are involved in, or their hobbies and outside interests. We could consider the chemistry involved in everyday issues, topical events that come up in the news media and in discussion; many of these topics are about the environment, energy and resources, and all involve science/chemistry, as well as economic, ethical and social issues. Figure 2 shows some of the possible areas of everyday chemistry.

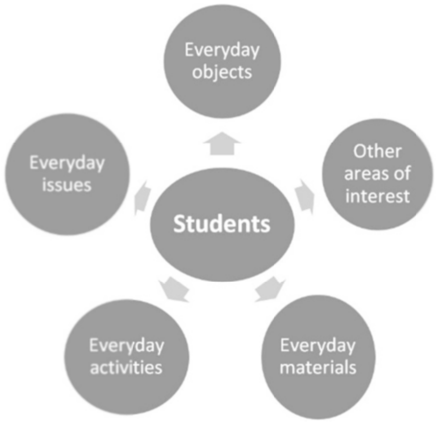

Figure 2. Possible areas of everyday chemistry

Everyday materials

In our everyday lives we use many materials for different purposes, which we usually take for granted and do not consider what life would be like without them. One interesting exercise is to get students to think what their day would be like without any products produced by chemistry. Examples include: paints, paper, metals, clothing, insecticides, food, fireworks, cosmetics, toys, plastics, building materials etc. This is similar to the topic-based approach used in the Salters' General Certificate of Secondary Education (GCSE) Chemistry course (Table 1). There are many topics that could be included and each one can bring in a lot of chemistry along the way. The specific topics would need to be modified to the particular country and culture in which the teaching takes place, and the approach of 'everyday chemistry' allows the starting points for introducing chemical ideas to be tailored to the specific situation, e.g. we might have a different selection of topics in European, Asian and African schools.

Table 1. Salters' GCSE Chemistry (Garforth, 1986)

Year (Grade) 9	Year (Grade) 10	Year (Grade) 11
Clothing	Transport	Burning & bonding
Drinks	Minerals	Electrochemistry
Food	Plastics	Keeping healthy
Metals	Agriculture	Energy today and tomorrow
Warmth	Food processing	
	Emulsions	
	Buildings	

Everyday issues

Another approach would be to investigate the chemistry/science involved in topical issues, such as: Genetically Modified (GM) crops and foods, nuclear energy, climate change, water pollution, fracking etc. The specific topics will change over time, but there are always controversial science-based topics in the media and public debate. Acid rain and ozone depletion have faded from public debate, but topics like climate change and fracking have replaced them. In this approach an issue being covered in the media is used as a starting point for an investigation of chemistry/science involved. These topics are hot issues and may be a matter under discussion at home. This is the approach taken in many of the Transition Year (TY) Science modules developed at the University of Limerick (see below). Many of the contemporary issues are environmental or resource-based and nearly all involve chemistry. However, when we get into real world issues the chemistry/science and the issues are often complex and interdisciplinary. Such issues allow the teacher to use newspapers and other media coverage in discussing the topic (see Jarman and McClune, 2007, for example, in using news media to teach science).

Another approach to everyday chemistry is to use advertising materials, which often make scientific claims (see Chapter 10 by Belova et al. in this book). The chemistry/science behind the claims could be investigated experimentally (e.g. which product cleans best or lasts longest?) and finding out the best value for money is a good example of consumer chemistry (Selinger, 1998; Emsley, 1994, 2007). What is the chemistry involved in formulating a medicine, a cleaning product, in soft drink, or processed food?

Everyday activities

From the time they get up in the morning students are involved in a variety of activities which have a scientific or chemical component. Such activities overlap with the chemistry involved in everyday materials and objects, but here the focus is on the activity in which the student is involved. Examples include, e.g., keeping clean, cooking, transport, sport, or entertainment.

Everyday objects

Everything we use every day has been made from raw materials, processed and fabricated in various ways. Thus the everyday objects we use can be the starting point for an investigation of the chemistry/science involved. Examples include: the car, the paraglider, the bicycle, smart phones, laptop computers, space rockets, gaslighters, contact lenses, batteries etc. Investigating how the object works, how it was made, what materials it was made from will uncover a wealth of scientific questions to be answered. In environmental impact analyses we often talk about ‘cradle to grave’ impact on energy and resources. We can do the same thing to investigate the cradle to grave story of familiar objects and the science involved.

Michael Faraday was a pioneer of relating science to everyday life, as illustrated by his popular lectures on 'The Chemical History of a Candle' given in 1848, which is a model of how to teach science through an everyday, familiar object. Table 2 shows the topics covered in his six demonstration lectures, which went on to be published and are still available online and in print (Halsall, 1998).

Table 2. The Chemical History of a Candle – lecture topics

Lecture	Topic	
I	A candle: The flame	Its sources Structure mobility Brightness
II	Brightness of the flame	Air necessary for combustion Production of water
III	Products of combustion	Water from the combustion Nature of water A compound Hydrogen
IV	Hydrogen in the candle	Burns into water The other part of water-oxygen
V	Oxygen present in the air	Nature of the atmosphere Carbonic acid
VI	Carbon or charcoal	Coal gas Respiration and its analogy to a candle

Another example is Thomas Huxley's popular 1868 lecture in Norwich on 'A piece of chalk', in which he explains to a lay audience the geology and chemistry of chalk (Huxley, 1868).

Other areas of interest

Everyday chemistry is also involved in other disciplines and areas of culture, which broaden the scope of everyday chemistry to include the social dimension of science to include economic, ethical and aesthetic issues (see the chapter by Garritz et al. in this book. These will involve the whole person, involving attitudes and values, rather than just the intellectual and practical skills we usually focus on. This approach could look at subjects such as: archaeology, art conservation and restoration, forensic science, history of chemistry, ethics, economics, conservation, resource management, space exploration etc.

TEACHING APPROACHES TO INTRODUCING EVERYDAY CHEMISTRY

The Salters' science courses and other context-based (or applications-led) courses start from everyday contexts and use these as the curriculum framework. The chemistry content is then introduced on a need-to-know basis to understand the context. Table 1 shows the topics used in Salters' GCSE Chemistry units. Traditionally in chemistry teaching, applications are left to the end of the chapter, almost as an afterthought; they may then be omitted altogether if the teacher runs out of time and may or may not be examined. Another approach is to sprinkle applications and everyday examples throughout the course, like chocolate chips in a muffin, so that the contexts are introduced on a nice-to-know basis. In context-lite courses like Organic Chemistry in Action! (O'Dwyer & Childs, 2012) a short chemical story, i.e., introduces the topic although the main focus is on the content. These approaches represent a spectrum of using everyday chemistry in the chemistry curriculum (Figure 3).

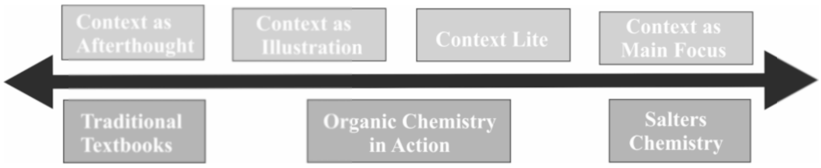

Figure 3. The everyday chemistry spectrum

In Tables 3 (a-f), we have tried to map examples of everyday chemistry onto the typical content of an upper secondary chemistry curriculum, such as might be done using context as an illustration or application.

Table 3a. Mapping everyday chemistry onto the curriculum (introductory chemistry)

Syllabus content	Everyday examples
Atoms, molecules, elements, compounds, mixtures	Lego blocks; cooking.
Atomic structure	Models, the world around us, differences in atomic structure of different objects
Radioactivity	Dating methods – carbon-14; age of the earth
Electronic structure of atoms/spectroscopy	Fireworks; colour of gems; northern lights; composition of stars
The Periodic Table – structure	Organisational charts
Oxidation and reduction/oxidation states	Corrosion; spoilage/oxidation of wine, foods
Types of chemical compounds	Food, medicines, clothing
Ionic bonding/compounds	Rocks and minerals
Covalent bonding/compounds	Cooking
Shapes of molecules	Smell and taste
Metallic bonding/metals	Metals and alloys
Molecular bonding/compounds	Smell and flavour
Materials and properties	Properties of materials linked to bonding
States of matter and properties	Water cycle
Gas laws	Bicycle pump; hot air balloons
The mole	
Chemical formulae	
Chemical equations	
Chemical nomenclature	

Table 3b. Mapping everyday chemistry onto the curriculum (solutions)

Syllabus content	Everyday examples
Solutions – saturated/unsaturated	Sugar in tea
Concentrations of solutions	Value for money
Water – structure and properties	Icebergs and frozen lakes
Hydrogen bonding	Fuels, medicines, biological functions (DNA, proteins), chelation
Water treatment	Purifying water; bottled waters
Sewage treatment	Waste treatment
Hardness of water	Washing; water softening
Dissolved gases; oxygen and BOD	Fish life; soft drinks
pH scale	Soil pH
Acids and bases	Household products; foods;
Strong and weak acids and bases	Food; household cleaning products, medicinal products (i.e. relief from stings),

Table 3c. Mapping everyday chemistry onto the curriculum (analysis and separation)

Syllabus content	Everyday examples
Volumetric analysis acids and bases	Analysis of household products
Volumetric analysis – redox	DO in water
Volumetric analysis – complexometric	Hard water; stalactites and stalagmites
Gravimetric analysis	Quality control in food; ores in industry; calibration
Instrumental analysis – AAS	Metals in water
Colorimetry	Fe and Cl_2 in water
Mass spectrometry	Quality control/analysis of drugs, food
IR spectroscopy	Quality control/analysis of drugs, food
UV-visible spectroscopy	Quality control/analysis of drugs, food
NMR spectroscopy	Quality control/analysis of drugs, food
Re/Crystallisation	Drug manufacture
Chromatography	Quality control of medicines
Distillation – ordinary and reflux	Drinks industry; desalination
Steam distillation	Perfumes

Table 3d. Mapping everyday chemistry onto the curriculum (organic chemistry)

Syllabus content	Everyday examples
Oil, refining and petrochemicals	Production of petrol
Aliphatic hydrocarbons – structure and properties	Natural gas; dry cleaning
Aromatic hydrocarbons – structure and properties	Synthesis of drugs
Carboxylic acids	Vinegar; citric acid; lactic acid
Alcohols	Drinks; biofuels
Esters	Food flavours
Aldehydes and ketones	
Organic Mechanisms	Production of medicine
Natural products	Food; drugs; dyes
Sugar and carbohydrates	Food industry; food tests
Amino acids and proteins	Food tests; good and bad fats
Pharmaceuticals	Pain killers
Soaps and detergents	Cleaning
Polymers – structure and properties	Plastics and their properties
Addition polymers	LDPE, HDPE,PP,PS recycling
Condensation polymers	Nylons; polyesters; fibres and clothes; wool and cotton

Table 3e. Mapping everyday chemistry onto the curriculum (physical chemistry)

Syllabus content	Everyday examples
Exothermic and endothermic reactions	Hot and cold packs; fuels; fridges
Bomb calorimeter	Food and fuels
Heats of reaction – energy diagrams	Hand-warmers used in sport; self-heating cans for drinks (e.g. coffee)
Energy and fuels	Value for money; pollution; climate change; rocket fuels
Entropy	How sugar dissolves in tea or coffee
Free energy	
Chemical equilibrium	Fizzy drinks, biochemical processes in our bodies
Equilibrium constants	Sun; photosynthesis
Le Chatelier's principle	Refrigerators, air conditioning systems
Electrochemistry – ions, cells	Batteries, electroplating of jewellery
Electrode potentials and electrochemical series	Sensors in industry, and for oxygen (pollution)
Batteries and fuel cells	Batteries –rechargeables; electric cars
Electrolysis (Faraday's laws) aqueous solutions and molten salts	Extraction of metals and production of NaOH, Cl_2

Table 3f. Mapping everyday chemistry onto the curriculum (inorganic and environmental chemistry)

Syllabus content	Everyday examples
Extraction of metals	Recycling metals
Reactivity series	Decision making in use of materials for differing purposes e.g. coolants, building
Corrosion	Rusting; prevention
Reactive metals (Group 1/I and 2/II)	Use in fireworks/pyrotechnics, coolants
Aluminium – amphotericity	Anodising
Transition metals – colour/oxidation states	Colour of gems; catalysis
Atmospheric chemistry	Pollution; climate change and CO_2;
Acid rain	Effects on soils, lakes, statues
Greenhouse effect	Climate change
Ozone depletion	Skin cancer
Photochemical smog	Asthma and cancer
Oxygen chemistry (Group 16/VI)	Combustion; respiration
Nitrogen chemistry (Group 15/V)	Fertilisers; explosives
Phosphorus chemistry (Group 15/V)	Fertilisers; food; detergents; pollution
Sulphur chemistry (Group 156/VI)	Air pollution
Fertilisers	Agriculture; organic food
Agrichemicals – pesticides/herbicides	Pollution
Chlorine chemistry Group VII/18)	Water purification
Hydrogen and hydrides	Hydrogen economy

However, it is better to start at the other end and identify areas of everyday life, particularly those of most interest or relevance to students' lives, as done in the *Salters' projects* and *Chemie im Kontext*.

Table 4 shows the approach taken by the *Chemistry and Society Teaching Project (PEQUIS)*, a Portuguese language project developed in Brazil from 1996 onwards (Dos Santos et al., 2006) and shows the nine modules developed over three years. In this case the Socio-Scientific Issues (SSI) content is introduced into the traditional chemistry curriculum, so that we are in the middle of our context spectrum. The authors say that rather than developing the chemistry from themes, "*the social themes evolve from the chemistry content because, otherwise, it would be too hard for chemistry teachers to accept it*" (p. 452). The course was developed for the final three years of secondary schooling, prior to university entry (see the chpter by Garritz et al. in this book).

EXAMPLES OF EVERYDAY CHEMISTRY

In this section we look in more detail at three ways of relating everyday chemistry to traditional chemistry content or introducing chemistry in an everyday context. Firstly, we look at some of the materials developed for the TY Science project. Secondly, we look at the topic of food and how chemistry content can be developed through it. Thirdly, we look at the topic of medicines and health and how this can be used to develop chemical ideas. Each of these examples is dealt with on its own, without reference to other topics or a whole chemistry curriculum. In designing a whole course, like *Salters' Chemistry*, the structure and sequencing of units would be important to develop the chemical ideas in a logical and sequential manner, where each unit (module) builds on those that have gone before. Our aim here is to show that it is possible to use aspects of everyday chemistry, starting from the students' own experiences, to develop traditional chemistry content, but in a more interesting and motivating manner.

Table 4. Chemistry and society modules and links to chemistry content (Dos Santos et al., 2006)

Year (grade)	Modules	Social themes	Chemistry content
1 (9)	Science, materials and waste	Waste	Science, chemistry, technology and society Materials and transformations Matter separation methods
	Particle models and air pollution	Air pollution	Activities of the chemist Study of gases and scientific models Atomic models
	Elements, bonding and agriculture	Agriculture	Chemical elements classification Ionic substances Molecular substances
2 (10)	Calculus, solutions and aesthetics	Aesthetics	Chemical units Chemical calculus Materials: classification and concentration
	Thermochemistry, kinetics and energy resources	Energy resources	Hydrocarbons Thermochemistry Chemical kinetics
	Chemical equilibrium and water	Water	Water properties and colligative properties Acids and bases Chemical equilibrium
3 (11)	Steels, cells and batteries	Steels	Metal bonding and redox Electrochemical cells Electrochemistry
	The organic chemistry of everyday life	Organic compounds and applications	Organic compounds Polymers Organic reactions
	Atom, radioactivity and nuclear energy	Radioactivity and nuclear energy	Electronic structure Stable nuclei and radioactivity Nuclear energy

Transition Year science

Since 2003 we have been developing science modules for the Irish Transition Year Programme (TYP), as part of the TY Science curriculum project. The TYP is an optional year between the junior and senior cycle in Ireland. There is no set curriculum or examination and this leaves teachers free to choose their own topics and teaching methods, within a set of broad aims and guidelines. However, Irish science teachers found themselves ill-equipped to take advantage of this opportunity to innovate and no materials for available specifically for this year. This led to the TY Science project to develop new materials, working in conjunction with final year pre-service science teachers, who designed, developed, implemented and evaluated the materials as part of their final year project (FYP) (Childs, Hayes, Lynch, & Sheehan, 2010). The result of this curriculum development project is a bank of low-cost teaching materials, which science teachers can use to teach outside the prescribed science curriculum and which offers them materials to bring the real world and everyday issues into the classroom. The TY Science materials have been well received and widely used by Irish science teachers (Hayes, 2011). Table 5 shows a list of the module titles developed from 2003-2014.

Table 5. List of TY Science modules

Name of TY Science Module	Year of development
Forensic science	2004
Cosmetic science	2004
The science of sport	2004
Science of survival	2007
Environmental science	2009
Issues in science	2009
Science and medicine	2009
Food science	2009
Space science & technology	2010
Science of cleaning	2010
Waste not, want not	2011
Power for the future	2011
Science of toys	2012
Smart materials	2012
More and more in less and less	2013
Scientific mysteries 1	2014

The development of scientific literacy through a focus on Science, Technology and Society (STS) is a key feature of these modules, which emphasise active learning and skill acquisition, including information technology and communication skills. They are not exclusively chemistry in content, as real world topics and issues are usually both complex and multi-disciplinary. However, most of the modules contain aspects of everyday chemistry. For example, in the module on *Issues in science*, one of the units is on the fluoridation of water. This allows the teacher and students to explore various topics: the source of fluoride compounds and how they are added to water; the analysis of water to ensure correct levels of fluoride; the structure tooth enamel and the role of fluoride ions in strengthening it; the evidence for the reduction of tooth decay when water is fluoridation; the counter evidence that high levels of fluoride may be harmful; the social issues of mandatory fluoridation versus personal choice (using toothpaste or mouth wash). In this module the approach in each unit is to first review the science behind the issue, then discuss the controversy and the pros and cons, and then have some forum where the students can have an informed argument about the issue.

Food for thought

The topic of food is an everyday contextual topic and lends itself to a number of chemistry concepts in the secondary curricula. By starting with a simple context, which is relevant to learners' everyday lives, this may help to provide a hook for engagement. From this starting point, learners can then move towards understanding the physical properties of food (colours, smells, tastes, cooking changes etc.) by developing an understanding of the chemical concepts that cause these changes. In this manner, the learner understands the macroscopic properties of food by developing their sub-microscopic understanding of chemical concepts.

As well as developing an understanding in chemistry, using a context such as food as a mechanism to teach chemistry also provides the learner with a knowledge *about* chemistry. For instance, having learned chemical concepts from this standpoint, the learner will be a better-informed citizen and better able to debate and have an educated opinion about wider global issues e.g. GM foods, organic foods etc.

Table 6 that follows is divided into four columns. The first column lists the main sub-topics relating to food. The middle column details the concepts of secondary level chemistry that can be taught through the particular topic. The final column provides examples of some of the possible activities that could be carried out by the teacher and /or learner. This list of possible activities is not extensive and is included here to stimulate further potential activities. The teaching methodologies for these activities have not been detailed as this is not the primary focus of this chapter. As can be seen from Table 6, there are some concepts which lend themselves to a number of different topics within the context of food. However, in each case, the important point is that the topic is introduced from the context; moving towards an understanding of the concept. Such over-lapping contextual links facilitate the development of a spiralling curriculum (Grove, Hershberger, & Bretz, 2008). By introducing new concepts to learners in a piece-meal 'need-to-know' fashion, the learners have a greater opportunity to develop a clearer understanding (Gravert, 2006). For example, learners could be introduced isomers through learning about amino acids (leucine and isoleucine), lipids (*cis* and *trans* fatty acids) or citric fruits (*d*-limonene and *l*-limonene). It should be noted that the order of the topics listed in Table 6 is not necessarily intended as a teaching order.

Table 6. Food: contexts, concepts and activities for teaching chemistry (part a)

Topic		Concepts	Ideas for possible activities
A source of energy	Conversion chemical energy to heat energy Comparison of carb. with fats	Heat of Combustion Bomb Calorimeter	Glucose ($C_6H_{12}O_6$) V Glyceryl trioleate ($C_{57}H_{104}O_6$): Glucose is more oxygenated, less energy-rich. 1g Glucose=17kJ, 1g Olive oil= 39kJ
	Alcohol- calories, energy	Fuels and oxygenates	Why are certain foods considered as 'less fattening'?
Cooking food	Teflon in non-stick cookware	Polymers Monomers Addition reaction	PTFE (polytetrafluoroethene) as a polymer: Identification of the tetrafluoroethene monomer. Reaction of PTFE with the compounds that make up food?
	The effects of heat: Physical changes Chemical changes	Organic synthesis Maillard oxidation reaction: carbohydrates and protein Irreversible reaction Enzymes Behaviour of organic substances	Investigation of the physical and chemical changes in the toasting of bread. Changes in protein tertiary structure: Enzymes lose shape, which leads to denaturation. E.g. denaturation of egg whites in whisking and cooking
	Baking Investigation of raising agents	Chemical equations Balancing equations Particulate nature of matter Heat	Comparison of baking soda, baking powder, cream of tartar, corn starch etc. Comparison of chemical composition Comparison of physical properties when used to make dough. Which dough raises the most? Why?
Food production	Production of glucose syrup Production of cheese Baking & Brewing	Enzymes Catalysts Rates of reactions	Investigation of yeast to break down hydrogen peroxide: Evidence that the gas collected is oxygen. Reaction rate depends on the amount of substrate. Vary the concentration of the substrate to show enzyme satura-tion. Vary the temperature of the reaction
	Fruit ripening	Ethene gas- test for unsaturation	Investigation to test for the production of ethene in ripening fruit- testing for unsaturation using dilute acidified potassium permanganate. One bad apple spoils the box. Is this true?

Table 6. Food: contexts, concepts and activities for teaching chemistry (part b)

Topic		Concepts	Ideas for possible activities
Food preservation	Tinned fruits	Denaturation of enzymes	Investigation of the fresh pineapple, frozen pineapple, tinned pineapple on prepared jelly (gelatine)
nutrients	Macronutrients - Proteins as natural polymers - Enzymes (reactions in the body) - Hormones (insulin) - Binding proteins (haemoglobin) - Amino acids - Carbohydrates - Lipids	Polymers Functional groups of organic compounds Isomers Polar and non-polar compounds Carbohydrates: carbon, hydrogen and oxygen Lipids: saturated and unsaturated Hydrogenation of alkanes to alkenes. *Cis* and *trans* isomers	Understanding amino acids: Non-polar side chains, polar chains, ionisable groups Compare leucine and isoleucine Recognising functionality in R groups- primary alcohols, secondary alcohols, phenols, carboxyl groups. Investigation of fats: Comparison of saturated and unsaturated fats-use chemi cal composition and bonding to explain their properties. Testing organic compounds: Burning foods to test for the presence of carbon. Teacher demonstration: Carbon tower (Sucrose and concentrated sulphuric acid).
	Food Tests - Iodine test for carbohydrates - Biuret test for proteins - Emulsion test for lipids	Use of starch as indicator in redox titrations Recognising carbonyl functional groups. Solubilities (polar and non-polar)	Carry out the test for starch on different carbohydrates: potato, bread, cereals, sugar Redox titrations where iodine is liberated Understand why the biuret test may give a colour change in the presence of a solution that is not a protein: what factor contributes to the colour change? Use emulsion test to explain that lipids are insoluble in water and soluble in ethanol.
	Vitamin C	Redox titration	Titration of vitamin C (ascorbic acid) with iodine to investigate the amount of vitamin C in different fruit juices.
Organic foods	Organic farming, fertilisers, pesticides, herbicides.	Distinguish difference between terms 'organic' chemistry and 'organic' food produce	Pupils develop an understanding of the term 'organic' within both contexts. Pupils debate the benefit of organic food produce.

Table 6. Food: contexts, concepts and activities for teaching chemistry (part c)

Topic		Concepts	Ideas for possible activities
Food additives	Natural colourings	Solvent extraction Paper chromatography Thin layer chromatography	Extraction of chlorophyll from spinach Separation of the extracted pigment using chromatography
	Artificial colourings	Thin layer chromatography Paper chromatography Solubility	Extraction and separation of artificial colours from prepared foods e.g. Smarties® etc.
	Natural flavours	Optical isomers Solvent extraction Liquid-liquid separation Polar and non-polar liquids Functional groups of the natural compounds	Comparison of oranges and lemons: *d*-limonene 'v' *l*-limonene- investigating the isomeric relationship between the essential oils that can be extracted from lemon peel and orange peel. Steam distillation extraction of food flavouring: Eugenol (clove oil)- followed by separation of the emulsion using cyclohexane. Extraction of other essential oils- natural food flavours: Vanillin, cinnamaldehyde, menthol, limonene etc.
	Artificial flavours	Synthesis of esters: Alcohols & carboxylic acids Condensation reaction	Test-tube synthesis of methyl butanoate (methanol and butanoic acid) to prepare apple / pineapple scent. Test-tube synthesis of propylethanoate (propanol and ethanoic acid) to prepare pear scent. These syntheses can also be modelled using molecular models to illustrate the condensation reaction.
	Sugar v salt	Ionic compounds Ionic bonding Covalent bonding Molecular compounds	Pupils carry out physical and chemical investigations to determine the differences between to the two similar white granules. Pupils illustrate the sub-microscopic differences despite the macroscopic similarities.
	Iron	Elemental chemistry Properties of compounds and mixtures	Extraction of iron filings from slurried breakfast cereal using a magnet.

Medicines and health

Yam (2008) describes context-based learning as:

> A conception of teaching and learning that helps teachers relate subject matter content to real world situations and motivates students to make connections between knowledge and its applications to their lives as family members, citizens, students, and workers. (n.p.)

The topic of 'Medicines and Health' utilises Context-Based Learning (CBL), placing secondary students' every day and life experiences and interests as an integral part of the lesson. This is vital in the science classroom as "*contextualisation improves access to knowledge*" (Peacock, cited in Campbell, & Lubben, 2000, p. 239). The topic of medicines and health is of particular relevance to students both in an Irish context and worldwide, with employment in the area a key area on the European and world-wide agenda. Linkages to employment and careers can "*encourage the development of skills, attitudes and routines relevant to the workplace*" (Campbell, & Lubben, 2000, p. 240). In addition science courses relevant to society may "emphasize socially and politically contentious content and encourage reasoning and decision-making skills appropriate for active citizenship" (*ibid*).

The reported benefits of this approach are the affective responses of the students to real-life situations, the gains in students' understanding, attitudes, and abilities (in some cases). The development of critical thinking skills for students can be developed in a context-based classroom (Bailin, 2002). Bailin (2002) argues that the premise of critical thinking is contextual, where learners are able to transfer knowledge from one context to another. Both the Relevance Of Science Education (ROSE) (Schreiner, & Sjøberg, 2005; Matthews, 2007) and the Programme for International Student Assessment (PISA) (Bybee, & McCrae, 2011) studies noted that secondary students are interested in science topics that are perceived relevant to them, and the 'human context' of science. medicines and health as a topic incorporates all these features. Another benefit of the CBL approach is the positive effect that it has on the gender balance in science (Bennett, Lubben, & Hogarth, 2007). However, there are distinct gender differences in terms of the contexts through which male and female students are interested in learning (Matthews, 2007; Bybee, & McCrae, 2011).

A context-based classroom can promote and enhance active student learning and integration of knowledge. Some of the issues that are claimed to be addressed by the context-based approach are: curriculum overload and fragmentation; the presentation of a curriculum as a body of isolated facts and concepts to be learned; the inability of students to transfer any scientific knowledge or skills beyond the science classroom (the context in which it was learned); curriculum content being irrelevant to students everyday lives, and a general confusion about why students should learn science, given its lack of relevance to their lives (Millar, & Osborne, 1998; Gilbert, Bulte, & Pilot, 2010).

The starting point of 'Medicines and Health' offers students a frame of reference for cross-curricular work and allows them to learn about a wide variety of chemical and scientific topics. In order to truly understand the pharmaceutical and chemical industry one must have a good knowledge of anatomy, biochemistry, organic chemistry, inorganic chemistry, engineering, business, and social sciences, thus this topic offers a broad scope for teaching and learning in the area of everyday life. This is shown schematically in Figure 4 and in more detail in Table 7.

Aspirin can be used as an example familiar to all students, yet one whose chemistry is relatively simple and amenable to synthesis in school (Lamont, 2009). It has an interesting social and scientific history, and it can be used to illustrate how a laboratory chemical can be manufactured on a large scale, packaged and distributed as a consumer product in different forms e.g. soluble and ordinary forms. The importance of chemical analysis and quality control can also be introduced, as well as the need to satisfy the regulations for drugs. The Royal Society of Chemistry (RSC, 2003) *Learn Chemistry* book uses aspirin as an example for a series of activities.

Figure 4 that follows Table 7 illustrates how the investigating a drug such as aspirin can lead to a wide variety of learning outcomes in chemistry. The figure is divided into six components, with each following a stage in the production of aspirin, as it is carried out in industry. This is not meant to be prescriptive, rather to illustrate how one drug can be taken and utilised through the context of manufacturing to learn about a broad range of chemical concepts and ideas. The broader context of the manufacture of medicines allows for cross-curricular linkages, which is very important in context-based learning about everyday chemistry, as it further reinforces the relevance of science in everyday life and the suggestion that developing knowledge and understanding is not the same as rote learning facts and figures (Carr, 2007; Kerry, 2011). The teaching methodologies which this topic can be taught through have not been detailed here, as it is beyond the scope of the chapter.

Table 7. Topics in medicine, health and drugs and how they link to chemistry of everyday life

Topic	Concepts	Ideas for potential activities
Bioavailability	Pharmacokinetics, solubility rates of reaction, density, molarity, redox and acid-base reactions, Volumetric analysis, yield, Hydrolysis, dissolution rates Chemicals in the body, bonding , pH, mathematical models, Ionisation	Preparation of sodium bicarbonate ear drops Preparation of antacid (i.e. milk of magnesia) Preparation of effervescent tablets Ingestion/adsorption of medicines: - Tablets (coated versus non-coated) - Creams/gels - Drops (eye/ear) - Liquid (suspension/solution)
Crystallisation in medicine	Rates of reaction Molecular structure Solubility, physical properties Organic chemistry	Preparation of copper sulphate crystals/alum crystals Recrystallization of benzoic acid and determination of melting point Recrystallization of aspirin and paracetamol
Nano in our body	Solubility Rates of reaction Particulate nature of matter	To make graphene/investigate graphite To make a titanium dioxide raspberry solar cell Demonstrate the particulate nature of matter using Lego© Serial dilution to demonstrate concentration
Medicine development	Chemical structure Risk assessment	Isolation of active organic compound in medicine Modelling molecules
Quality analysis	Solubility, acid-base reactions, rates of reaction Volumetric analysis Standard solutions	Chalk chromatography Paper chromatography & spin chromatography Analysing medicines using colorimetic measurements Isolation of active organic compound in medicine
Process control	Risk assessment, thermodynamics solubility, physical and chemical properties, feedback systems	Baking chocolate chip muffins (as an analogy for making a medicine) - Chocolate chip: size, dispersion, physical properties (pre and post cooking) - Muffin mixture – consistency pre and post cooking (i.e. even cooking) - Batch consistency between the class groups

Figure 4. Illustration of how drug can be utilised to teach a variety of different chemical concepts through different activities

CONCLUSION

The beauty of everyday chemistry as a theme is that it is literally all around us, every minute of the day and in every location. If we are looking for relevance in chemistry teaching in everyday contexts then there is no shortage of examples. We have shown that there are various ways of approaching this topic and have given some brief examples to illustrate it. The best and most effective approach is to restructure the chemistry curriculum around everyday topics, as in the Salters' science projects. Many countries do not have the freedom to do this and must work within the confines of a centrally-prescribed curriculum and examination. In this case the best approach is to infuse examples of everyday chemistry into the different topics, using them to introduce topics and to illustrate the theory as it is introduced. The least effective way is to add on examples at the end of a topic, where they are seen as an afterthought and often ignored. To be most effective the assessment of a course must include examples of everyday chemistry, indicating to students and teachers that this is an important aspect of the chemistry course. Many students are put off chemistry because it is seen as boring and irrelevant to everyday life. Making everyday chemistry a core feature of the chemistry course offers a way to increase students' interest and motivation for studying chemistry at school.

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HANNAH SEVIAN AND ASTRID M. W. BULTE

4. LEARNING CHEMISTRY TO ENRICH STUDENTS' VIEWS ON THE WORLD THEY LIVE IN

Practicing chemistry involves using chemical knowledge to evaluate benefits, costs and risks associated with products and processes, and to make informed decisions based on reasoned evaluation. Traditional topical approaches to teaching chemistry have been demonstrated to be unsuccessful in providing students such opportunities. Context-based approaches address this; however, to establish stronger effectiveness, a theoretical underpinning is necessary. Starting from Roberts' curriculum emphasis concept, we argue that if students are to develop useful chemical knowledge, they need a clear view on how the chemistry they learn is related to their lives and the world they live in. In other words, the learning environment needs to be positioned in a clearly defined curriculum emphasis. This determines deliberate focus on enriching students' engagement with chemical thinking in real-world problems. Curriculum emphasis can be related to division of labor for different chemical practices, such as a technologist developing new materials for biomedical purposes, a citizen deciding what kind of fuel to use, or a scientist investigating mechanisms of catalysts. Each practice has specific relevance and, consequently, different foci in the content of chemistry. When a certain emphasis or sequence of emphases is chosen for a particular stage in students' learning, a thoughtful co-development of instructional approaches and assessment of students' progress toward using chemical knowledge is required. We provide exemplars of units positioned within a certain emphasis, and show how the curriculum emphasis model shapes curriculum development, as well as development of assessment within the chosen emphasis.

INTRODUCTION

Chemistry presents a unique position among the sciences as an area of study in which students have opportunities to consider consequences of actions with personal and societal ramifications, both in the present and for the future. In particular, chemistry education can offer students opportunities to practice using chemical knowledge to evaluate benefits, costs and risks associated with products and processes, and to make informed decisions based on reasoned evaluation.

These opportunities are presented, in large part, through the emphases embedded in the science curricula, which, in turn, are chosen for students by their teachers and/or by the larger educational system. For our discussion of relevance,

I. Eilks & A. Hofstein (Eds.), Relevant Chemistry Education – From Theory to Practice, 55–78.

we use the curriculum emphasis concept as described by Roberts, who defines a curriculum emphasis as "*a coherent set of [meta-]messages to the student about science (rather than within science) ... constitut[ing] 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).

The concept of curriculum emphasis can be illustrated with two examples (Van Driel, Bulte, & Verloop, 2005). Consider the following chemistry topic: calculations in chemistry, more specifically, the principle that two chemicals react in fixed mass ratios and that during such a chemical reaction the total mass is conserved. This topic can be treated in completely different situations with completely different meta-lessons, that is, curriculum emphases:

- *Science, Technology and Decisions*: Within this emphasis, a possible approach could include a classroom discussion about the safety regulations for the use of food preservatives; for example, 'How much sulfite is required to preserve white wine, and how much is safe?' Students would investigate the properties of chemicals and search for explanations. This occurs in light of a socio-scientific question. Students would receive the following meta-message about the school subject: There is a socially and/or personally relevant question, and chemical knowledge is needed to find an answer.
- *Self as Explainer*: An approach within this emphasis might consist of students doing experiments and finding out that the same 'law' applies in different circumstances. Students would carry out experiments and calculations to discover themselves the same chemical foundations as Lavoisier found in the eighteenth century. An implicit meta-lesson of this approach would be to show students that, just as they themselves did, chemists throughout history were able to discover certain laws that can be considered important foundations of present-day chemistry.

Using Roberts' curriculum emphasis concept, the aim of this chapter is to illustrate how conceptual thinking in chemistry can come to the fore, and focus students' attention on different dimensions of relevance, including personal, societal, and vocational, considering present and/or future, and with respect to the student's own needs as well as those of a larger society (Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013).

We start by first providing a framework of chemical thinking with six crosscutting disciplinary concepts of chemistry. Second, we select one of these concepts for further elaboration (benefits-costs-risks thinking), because this concept is underrepresented in traditional chemistry curricula. In this second part, we discuss consequences for assessment in relation to this essential, but so far less investigated, concept. From there on, in the third part, we illustrate how chemical thinking can be built by deliberate choices of activities and themes that determine curriculum emphases. Through examples drawn from this suggested curriculum, the core ideas of chemistry are highlighted, and assessment examples are presented for the concept of benefits-costs-risks thinking.

RELEVANCE OF CHEMISTRY AS A DISCIPLINE

When discussing chemistry education, it is important to consider how chemistry functions in society and in the academic discipline. Chemistry has evolved as a discipline whose aims include meeting needs of humans as well as explaining and predicting nature through theoretical models. In other words, chemistry is a technoscience that merges the pursuit of scientific knowledge with technological goals driven by human needs and conditions (Chamizo, 2013). Thus, essential questions that guide the discipline involve not only 'What can we know?' but also 'What can we do with what we know?' (Talanquer, 2013). Central in chemistry is to analyze, synthesize and transform matter for practical purpose (NRC, 2003). Chemical scientists engage in blended scientific and engineering practices that involve not only explaining and predicting the properties of matter, but also designing, applying, and evaluating methods and strategies to pursue the practical aims of synthesizing, analyzing and transforming matter.

The knowledge, reasoning and practices of chemistry can be expressed as *chemical thinking* (Talanquer & Pollard, 2010). This had led to a chemical thinking framework to guide curriculum, instruction and assessment in chemistry (Sevian & Talanquer, 2014). This framework considers six crosscutting concepts of the discipline of chemistry, each of which answers a central question in the application of chemical knowledge to practicing the discipline of chemistry (Table 1). Each of the concepts A-F is associated with progress variables (PVs). However, every progress variable has some associations with all of the concepts. For example, chemical identity (concept A), which uses the theoretical idea of *substance* as able to be uniquely identified and therefore distinguished from other substances, is certainly a necessary construct in considering how and why chemical processes and reactions occur (concept C). Likewise, benefits-costs-risks reasoning (concept F) is relevant to all chemical thinking, which we expand upon below. The deliberate language in Table 1, acknowledges that 'substance' is a theoretical construct, while 'material' is a phenomenological idea. That is, nearly every kind of 'stuff' that we encounter is made of materials that are combinations of substances. Furthermore, 'material' has different meanings at different spatial scales. For example, wood is a material. It consists of several substances in different specific arrangements at various meso-levels to make the material (Meijer, Bulte, & Pilot, 2013).

Besides the other core aspects of chemical thinking, *benefits-costs-risks* thinking (concept F; Table 1) is central to chemical thinking. Chemistry has profound consequences for our lives and in our world. Beneficial outcomes of chemistry include products, such as medicines and polymeric materials, that improve the quality of life, and processes, such as fossil fuel combustion and semiconductor device fabrication, that transform the ways we live. There are associated costs and risks that affect our health, society, and the environment. Therefore, engagement in chemical thinking that addresses human needs should include the evaluation of social, economic, and environmental benefits, costs, and risks associated with chemical products and processes. Explicitly addressing this concept would address general negative associations with chemistry by society uncovered by the Eurobarometer study (European Commission on Public Health, 2013).

Table 1. Crosscutting disciplinary concepts of chemical thinking (A-F), with progress variables identified as essential questions asked by chemical scientists and chemistry students as they do chemistry (adapted from Sevian & Talanquer, 2014)

Crosscutting disciplinary concept and core question answered	Progress variables (PVs) as essential questions
A. Chemical identity How do we identify substances?	**PV1**: What types of matter are there? **PV2**: What cues are used to differentiate matter types?
B. Structure-property relationships How do we predict the properties of materials?	**PV3**: How do properties of matter types emerge? **PV4**: How does structure influence reactivity?
C. Chemical causality Why do chemical processes occur?	**PV5**: What drives chemical change? **PV6**: What determines the outcomes of chemical changes?
D. Chemical mechanism How do chemical processes occur?	**PV7**: What interaction patterns are established? **PV8**: What affects chemical change?
E. Chemical control How can we control chemical processes?	**PV9**: How can chemical changes be controlled? **PV10**: How can the effects be controlled?
F. Benefits-costs-risks How do we evaluate the impacts of chemically transforming matter?	**PV11**: What are the effects of using and producing different matter types?*

*PV11 also connects to Chemical Identity

RELEVANCE OF BENEFITS-COSTS-RISKS THINKING IN CHEMISTRY

An approach to learning chemistry that emphasizes benefits-costs-risks thinking (concept F, Table 1) connects chemistry learning to the students' worlds in which they live. The inclusion of this concept is in line with Stuckey et al. (2013) arguing that, across many decades of reform, science education has evolved to a view that connects the value of learning science to the consequences, both positive and negative, of having and using scientific knowledge. Benefits-costs-risks thinking is defined as the consideration of the consequences of using and producing matter. This aspect of chemical thinking (see Sevian & Talanquer, 2014, and Table 1) deserves special attention, because it is underemphasized in most chemistry curricula. Benefits-costs-risks thinking occurs when people are challenged to evaluate options and make decisions, with some basis in chemistry knowledge, about issues that pertain to individuals and/or society. Such activity often involves consideration of social, environmental, economic, and ethical factors. For example, educated citizens must make value-laden choices about what counts as evidence, just as they also make decisions about when to suspend beliefs and hedge on what they consider to be sufficient evidence. Climate change is a relevant modern example in which this activity is present in nearly every consideration by the public about issues. Kolstø (2001) suggests that engaging in such thinking empowers students to consider their own human needs as well as those of society more generally. He has proposed eight content-transcending topics for educating future citizens to make decisions about issues that have scientific dimensions. He groups the topics under four themes in which knowledge is used as a tool for evaluating and decision-making:

1. Science as a social process theme
   - Science-in-the-making and the role of consensus in science
2. Limitations of science theme
   - Science as one of several social dimensions
   - Descriptive and normative statements
   - Demands for underpinning evidence
   - Scientific models as context-bound
3. Values in science theme
   - Scientific evidence
   - "Suspension of belief"
4. Critical attitude theme
   - Scrutinize science-related knowledge claims

Assessment of benefits-costs-risks-thinking

The examples of assessment discussed in this chapter focus on benefits-costs-risks thinking to illustrate ways in which teachers may help students to develop greater capacity to use chemical thinking in their own worlds. Controversies in which science knowledge is relevant can be productive jumping-off points for asking students to apply scientific knowledge in thinking, because they must consider consequences of activity in light of certain (assumed) conditions. Benefits-costs-risks thinking can be assessed through asking students to select the best (or worst) from among several options that each have strengths and drawbacks in several dimensions, and where there is not one "correct" answer. Rather, the answer depends on how the student interprets the data, what chemical knowledge the student applies, and how the student argues the choice. The information about strengths and drawbacks may be provided all at once or gradually, and may include information that could be interpreted as having ramifications for health, environment, financial cost, or ethics. Kolstø's eight content-transcending topics provide a good jumping-off point for selecting assessment questions, because they are designed to offer opportunities for controversy.

It is important to be able to recognize differences between intuitive vs. academic thinking about benefits, costs and risks (Cullipher, Sevian, & Talanquer, 2012), in order to successfully engage students in purposeful activity in which students develop more sophisticated benefits-costs-risks thinking. Recognition of these differences can enable chemistry instructors to assess students' current understanding, so that students may be guided toward asking questions, evaluating potential consequences, and making decisions using chemical knowledge in increasingly sophisticated ways.

Intuitive toward more sophisticated benefits-costs-risks-thinking

There is very little research directly examining students' views of benefits, costs and risks in learning chemistry. However, many studies have examined how students consider chemical processes in the context of modern concerns, such as effects on ecosystems and climate change (e.g., Mohan, Chen, & Anderson, 2009). In addition, research on risk perception research in psychology and risk assessment in economics and environmental science has shed light on differences between lay and expert perceptions of chemical problems. Examples include hazardous waste cleanup (Siegrist & Cvetkovich, 2000), health risks with chemical exposure (Kraus, Malmfors, & Slovic, 1992), and water quality (Dobbie & Brown, 2014).

These studies show that laypersons tend to exhibit strong preferences and biases when making decisions that involve consideration of benefits, costs and risks. For example, in alignment with the results of the Eurobarometer study mentioned earlier, people often ascribe negative connotations to "chemicals", perceiving all chemicals as manmade and potentially dangerous. Slovic (2010) identifies two primary factors that influence people's risk perception. Dread risk is characterized by how much a person perceives there to be a lack of control, disastrous potential, fatal consequences, or inequitable distribution of risks and benefits. Unknown risk is characterized in terms of a person's assessment of how unobservable, new, or delayed the risk is in its manifestation of harm. Laypersons often selectively credit or dismiss evidence of benefits, costs, and risks based on personal values that they share with others rather than on scientific knowledge (Kahan, Jenkins-Smith, & Braman, 2011). Students have also been found to rely on emotional and rationalistic thinking when analyzing socio-scientific issues, regardless of their level of content knowledge about a subject (Sadler & Donnelly, 2006).

Much less has been studied about how students' thinking about benefits, costs and risks advances with training in science. Some research has shown that students' abilities to generate high-quality costs, benefits, and risk analyses seem to vary nonlinearly with content knowledge acquisition (Sadler & Fowler, 2006). Such behavior may partially be explained by the observation of Kahan et al. (2011) that personal values interfere with the interpretation of evidence.

In relation to students' benefits-costs-risks thinking in chemistry, two overarching variables of sophistication in chemical thinking can be categorized (Cullipher et al., 2012): complexity of analysis and proximity to self. In the first of these, it was found that novices tend to isolate a single factor, either related to personal experience or taken as fixed (certain and unquestioned) knowledge from the data provided, that influence the student's evaluation (a dichotomous view), whereas more complex reasoning considers multiple factors and even tradeoffs (a balanced view). This is consistent with the complexity framework derived by Bernholt and Parchmann (2011) in studying students' knowledge in chemistry. These researchers showed that five hierarchical levels of complexity occur in students' achievement when they are presented with tasks requiring reasoning in chemistry: 1) descriptions based on everyday experiences and explanations related to familiar examples, 2) explanations based on reproduced facts that have been learned, such as oxygen being necessary for combustion, 3) descriptions of phenomena and processes chronologically, such as reaction mechanisms, 4) linear causal explanations that elaborate mechanisms, such as where soot comes from when something burns, and 5) reasoning with multivariate interdependencies, which might include nested variables or feedback loops.

In the 'proximity to self' variable, when considering consequences, more novice students primarily focus on one spatial degree of proximity (self, others/surroundings, society/global) and one temporal degree (now, soon, within one's lifetime, future generations), while more sophisticated approaches tend to consider multiple degrees both spatially and temporally. This is consistent with two of the three dimensions (intrinsic vs. extrinsic, and present vs. future) in the relevance framework proposed by Stuckey et al. (2013).

Some insights about levels of sophistication in applying benefits-costs-risks thinking to a particular controversial problem can be gleaned from a study in which Cullipher, Sevian, and Talanquer (2015) asked students from first-year through fourth-year university level to select the best fuel for use in powering a GoKart (a small vehicle in which children can ride that has a fuel-powered engine). Four fuels were offered as options: gasoline derived from petroleum, gasoline derived from wood pellets, a fuel called E85, and natural gas. Students were told that gasoline is mostly made of octane, E85 is mostly ethanol, and natural gas is methane. More information was progressively provided during the interviews, and at each juncture, students were asked to say which would be the best fuel for the purpose, and to justify their choice. After the initial question, the progressive additional information provided was a) phases of the fuels, b) elements from which the fuels are comprised, and c) structures of the main component substances, shown as labeled ball-and-stick diagrams. Finally, students were asked to consider that all of the fuels contribute to pollution, and then asked which fuel would impart least damage to the environment.

Reasoning patterns observed ranged from intuitive (corresponding to least complex in the framework of Bernholt and Parchmann, 2011) to academic (most complex). These were exhibited along several approaches: component characteristics, pollution, practicality and energy. More complex reasoning generally included several approaches interwoven. Examples of arguments within each approach, and at three levels, are shown in Table 2.

Table 2. Examples of intuitive, intermediate and academic levels of reasoning within four approaches observed in reasoning about best fuel to power a GoKart

Approach to the problem	Level of conceptual sophistication Intuitive	Intermediate	Academic
Component characteristics	Natural gas is the best fuel because "natural" things are good for the environment.	Smaller molecules combust more efficiently.	Octane from wood pellets is a better fuel source than ethanol from wood, due to synthesis routes and the state of technology.
Practicality	Gases (or liquids) are easier to store and transport than liquids (or gases).	Gases have to be converted to liquids to be used as fuels.	There is a cost associated with using a gas fuel because it would require changing the infrastructure of the system we currently use to store and transport fuels.
Pollution	The more carbon present in the molecule of the fuel, the more CO_2 is produced.	The byproducts of octane combustion could include other alkanes (pollutants) but the products of ethanol combustion will always be CO_2 and water.	The amount of CO_2 produced must be compared to the amount of energy produced per mole of the fuel.
Energy	A larger molecule will last longer and therefore make an engine run longer than a smaller molecule.	Larger molecules release more energy during combustion.	The change in the oxidation state of carbon governs the theoretical energy production.

In general, intuitive reasoning is characterized by the consideration of substances or materials as objects, while more sophisticated academic reasoning is based on scientific models that account for interactions among molecules or regions in various meso-level structures. Intuitive reasoning tends to be marked by considering surface features and assuming substances behave the same at all scales. For example, the intuitive reasoning that larger molecules make engines run longer rests on a rationale that longer objects contain more "stuff" and thus last longer as they burn. Intermediate reasoning tends to occur as a hybrid between intuitive and academic reasoning, sometimes with scientific models interpreted in an intuitive manner. For example, the intermediate reasoning that smaller molecules combust more efficiently recognizes that a methane molecule has fewer bonds than an octane molecule, but also combines this thinking with an intuitive notion that the greater surface area afforded by having smaller particles would make the reaction occur more quickly.

Within suggestions we present below of curriculum emphases, we offer examples of different levels of sophistication in students' benefits-costs-risks thinking in confronting controversies in which chemistry knowledge is relevant.

PROPOSAL FOR CURRICULUM CONSTRUCTION: LEARNING PROGRESSION, RELEVANCE AND CHEMICAL THINKING

While we recognize the discipline of chemistry as having societal relevance, conventional approaches to teaching chemistry tend to present the discipline as a collection of facts and concepts to memorize and perform, such as writing electronic configurations, using the octet rule, and balancing chemical equations. These approaches do little to help students connect chemistry knowledge to more fundamental ideas in chemistry, such as that bonding results from interactive forces (Levy Nahum, Mamlok-Naaman, Hofstein, & Kronik, 2008; Taber, 2013). Consequently, traditional approaches fail to communicate relevance to students. Roberts relates analyses of curricula with such traditional approaches as primarily having *Solid Foundation* and *Correct Explanation* emphases. Such approaches are considered by Stuckey et al. (2013) to relate to extrinsically defined dimensions of individual and vocational education.

Chemistry educators have recognized a need to also connect the use of chemical knowledge to authentic chemical concerns in students' lives (Bulte, Westbroek, de Jong, & Pilot, 2006). Context-based approaches – such as *Chemie im Kontext* (Nentwig et al., 2007) in Germany, *Salters' Chemistry* (Bennett & Lubben, 2006) in the UK, and *ChemCom* (ACS, 2012) and *Chemistry in Context* (ACS, 2011) in the US – introduce chemical knowledge on a need-to-know basis in the context of real-world problems. These approaches have seen some success in meeting the challenge of getting students to connect chemistry to real-world issues. In particular, context-based approaches have been shown to contribute to increased attitudes toward chemistry (Gutwill-Wise, 2001) and conceptual understanding under some circumstances (Fechner, 2009). However, there is a need for a rationale to come to an outline for a chemistry curriculum, and to develop some guidelines for how the progression of learning chemistry can be related to different dimensions of relevance. The illustration in the introduction shows how the learning of chemistry can communicate different meta-messages on 'relevance'. Such examples do not give guidelines and hints about what emphases in what sequence may be appropriate for students with a certain ability level and a certain age.

Therefore we intend to show how Roberts' emphasis concept can be connected to a particular learning progression of chemical thinking. By 'learning progression', we mean an affective and cognitive model of how learners' interest, understanding and reasoning evolve over time. Generally, learning progressions identify a lower anchor, which includes a characterization of the interest, knowledge and reasoning of students at the start of the learning progression, and an upper anchor. The upper anchor is often scientifically directed interest and accepted models, although, it could be models that are less accurate scientifically. Most importantly, such a conception of 'learning progression' is much more than a scope and sequence of content logic through a series of more sophisticated canonical models and normative knowledge in science. Rather, many learning progressions consider 'stepping stones' of intermediate levels that are productive ways of thinking along the way toward the upper anchor (Duncan & Rivet, 2013; Wiser, Frazier, & Fox, 2013). Learning progressions also must relate to the experienced relevance of thinking in the discipline. They should consider affective aspects as well as cognitive aspects of the discipline. Progress must occur in interest in and realization of relevance of certain activities in the discipline.

Roberts (1982, 1988) recommends to avoid intermingling different curriculum emphases within one teaching unit (i.e., within one text book chapter or one module). In relation to the issue of relevance, we believe it is important to avoid student confusion for two additional reasons:

- To engage students in the learning of chemistry requires a clear dimension of relevance;
- To ensure a meaningful connection between the setting, or context, and the learning of specific chemistry content, it is important that students clearly understand the learning goals.

It has been argued (Bulte et al., 2006) that an authentic chemical practice in itself can provide a starting point for a consistent curriculum emphasis for one teaching unit (Prins, Bulte, van Driel, & Pilot, 2008). All around us, many chemistry-related practices are available, such as quality evaluation of products (e.g. drinking water, food, or consumer products for personal health) and practices with an emphasis on research (e.g., developing new catalysts or acquiring fundamental understanding of structure–property relations of proteins). An authentic practice is defined as a group of people who interact with each other and work on real-world problems and societal issues in a 'community' connected by three characteristic features:

- Members of the group have common motives and purposes (e.g. evaluation of the quality of a product or development of a new product);
- They work according to similar characteristic procedures leading to an outcome (e.g. a procedure for quality assessment or design procedure); and
- They display apparent necessary content knowledge about the issue they work on.

For example, an authentic practice of veterinarians includes dealing with the curing of sick animals. Science teachers and hospital lab technicians also share authentic practices. Within authentic practices, specific attitudes, characteristic procedures, and content knowledge play a natural role. The relevance of the skills and content knowledge involved is not questioned, since the people engaged in the practice have clear motives to use and extend these accordingly (Van Aalsvoort, 2000).

If students are actively involved in a learning process that resembles an authentic practice, and in which they take an active role performing activities within the practice, they are expected to appreciate the implications of the concepts and give those concepts appropriate meanings. Authentic practices then can be used as sources of inspiration for designing a learning process such that students see the point of what they are doing and have motives for extending their chemical knowledge (Lijnse & Klaassen, 2004). Use of such an authentic practice implies an emphasis that communicates a specific dimension of relevance in chemistry education (Stuckey et al., 2013).

General outline for a chemistry curriculum

Table 3 provides a summary of how a chemistry curriculum (e.g., ages 8 to 18) could roughly be outlined, based on the notion that a consistent choice for one (authentic) chemical practice for one teaching unit implies a certain curriculum emphasis. In offering this example, we intend to suggest broad guidelines for what types of practices, and in what sequence, would be appropriate for different ages of students, thereby providing students with different dimensions of relevance. For designers of a curriculum, this may offer guidance for sequencing. For teachers, this may offer suggestions for ways that teachers can guide students' learning progress through the selection of curriculum emphases.

The first column of the table shows types of practices as proposed by Sevian and Talanquer (2014). Here they are sequenced as Producing → Evaluating → Designing → Researching. This specific sequence is argued in the next sections. Our view is that the choice of a theme in combination with a particular activity is the practice. For example, the first cell shows a theme of food with an activity of producing, and together these comprise a practice of figuring out what something is made of. Examples of these practices, and their connections to curriculum emphases, are elaborated below. In each row connected to a specific activity (e.g. producing), then, different themes can be chosen. Each cell's theme is a lead theme for one teaching unit. The whole set of themes (very likely to be more than the three examples shown in Table 3) within one row should then gradually build up the intended chemical ideas which should match with students' interests and students' abilities, for example for one year, or one specific period of chemistry teaching. At the end of each of the rows, the curriculum could be designed to have students experience the need for a next type of activity. This brings students from the less complex activity 'producing' to a more elaborate activity 'evaluating', etc. The idea is that producing and dealing with objects and materials around them is in students' zone of proximal development (Vygotsky, 1978) when they start their chemistry or science education, whilst thinking about the quality may be a bridge too far in the beginning, but lies within the zone of proximal development after several teaching units about producing. Then there should be an affective 'stepping stone' to think about the evaluation of the quality of products.

Table 3. A broad curriculum outline to connect characteristic activities of chemistry to chemical thinking

Type of activity	Exemplary theme (likely to be more than three)			Concepts	Curriculum emphasis
Producing	Food-1	Food-2	Goods-1	'stuff' objects, materials, ingredients (A & F)	Everyday coping
Evaluating quality	(Drinking) water	Food-3	Goods-2	'quality' in terms of components: substances; elements (A, B & F)	Science, technology and decisions
Conceptual designing (synthesis)	Food components	Drugs	Electronic devices	building blocks (molecules; atoms) (A-C & F)	Rational materials development
Researching/ inquiry	Food and health		Nano	'modeling' as the product of doing science (A-F)	Structure of science

The next sections, for each of the rows, describe the argumentation behind this outline, which connects this outline to one or two of the Roberts' emphases, to aspects of chemical thinking, to the framework of Stuckey et al. (2013) for individual, societal and vocational dimensions of relevance, and to the progress variables of the chemical thinking learning progression shown in Table 1. Each of the sections also describes the specific view of the teachers, in coherence with the view of science, the view of the learning, and the view of society.

Producing

The first type of activity, producing, refers to many of the authentic practices in society in which products for consumers are produced by putting ingredients together. The food sector is one area in which this occurs, but it also occurs in the production of many manmade daily objects, such as clothes, plates and cups, paper, furniture, fabrics, etc. Initial chemistry education could be based on the practice of producing such products, and could relate to the objects in our lives as a starting point by asking the relevant question, "Where do these come from?" Depending on the lower anchor anticipated, and the learning goals, the focus could be on different aspects of materials, which are the goals for intermediate levels in the learning progression.

When early years of primary education are the starting point, the human activity of producing would start with a focus on the results of production activities; that is, questioning what products we have around us, such as juice (Food-1), the bubbles in carbonated beverages (Food-2) or the cups the children drink from. Foregrounded in such activity about matter and materials are ideas of properties, and distinguishing between solid and liquid. At a very basic level, children could develop a notion that, for certain applications, some materials are more suitable than others. This engenders a view of science according to the curriculum emphasis of *Everyday Coping* (see Table 4). Such chemical thinking is aligned with recommendations made by Wiser, Frazier, and Fox (2013, p.100-101) for younger children, grades K-5 (ages 5-11). We emphasize that it is important to consider ways in which younger children think because these reasoning patterns are often still present, and certainly get built upon, in older children. The Food-1 and 2 activities outlined above confront children with materials as distinct classes of stuff, and the functional usage of materials. Through these activities, in accordance with the research of Wiser and colleagues (2013), children's chemical thinking can grow in sophistication from considering weight as 'heft' toward the idea of weight as an extensive property, such that heavy objects are differentiated from heavy kinds of materials, and from considering amount of material as the size or shape of an object toward the idea that matter is conserved across physical changes. At a more sophisticated level, a transformation of thinking takes place to consider materials as constituents of objects (Sevian & Talanquer, 2014).

Table 4. Views of science, the learner, the teacher, and society in Roberts' curriculum emphasis of Everyday Coping

Curriculum emphasis	View of science	View of the learner	View of the teacher	View of society
Everyday coping	A meaning system necessary for understanding and therefore controlling everyday objects and events	Needs to master the best explanations available for comfortable, competent explanation of natural events, and control of mechanical objects and personal affairs	Someone who regularly explains natural and manmade objects and events by appropriate scientific principles	Autonomous, knowledgeable individuals who can do (mechanical) things well, who are entrepreneurial, and who look after themselves, are highly valued members of the social order

In later levels of primary education, the themes may assume a more advanced level. A core assumption could be producing foods and goods as a starting point for the introduction of chemical thinking with respect to chemical identity (PV1 and PV2 in particular; Table 1), structure-property relationships (PV3 in particular), and benefits-costs-risks (PV11 in particular). This may also be effective even if initial chemistry education only begins at an older age (e.g., in the Netherlands chemistry education begins at age 14-15 in secondary education).

Compared to Roberts' emphases, this type of practice is most closely related to *Everyday Coping* (Table 4). Roberts describes this for both the personal dimension (the view of the learner) and the societal dimension (view of society). In the present, a child may satisfy his or her personal curiosity and interest in different daily life objects, and explore different properties of those objects. For the child's future, abilities to distinguish different materials for different uses implies coping with personal life. In relation to the societal dimension, immersion in such a practice could give a child an idea about how products in society are produced, and what dilemmas a producer may face. Furthermore, knowledge about different production practices can broaden the child's future professional horizons.

Assessment of children's growth in sophistication of thinking can occur by presenting students with questions or performance tasks that are consistent with the *Everyday Coping* emphasis, and that give them opportunities to apply chemistry ideas to the practice of producing. If the concept of benefits-costs-risks thinking is to be assessed, children could be asked to confront questions of the consequences of using and producing matter. Examples of this might be making decisions about which kind of yogurt to eat for lunch, whether whole milk or reduced fat milk may be more likely to spoil faster, or if refrigerating cheese matters in preserving it. Children might be asked to make choices among different starting materials that could be used to make disposable paper cups, if they live in a region where paper production is a relevant economic reality, or ceramic mugs, if they live in a region where ceramics are produced. Older children might be asked to consider the consequences of different processes of paper or ceramics production.

Assessment of chemical thinking throughout a multi-year chemistry curriculum can aid teachers in determining levels of cognition along the learning progression of each student's chemical thinking, and what may be appropriate challenges that teachers can challenge individual students with to help move them forward. For example, within an emphasis of *Everyday Coping* in considering the production of different foods, if a student demonstrates dichotomous reasoning based on familiar experiences that are entirely personal, the student might be challenged to conduct a survey with several friends or neighbors to find out what experiences other people have that may result in different decisions, to expand the student's horizons to consider a slightly larger idea of society.

Evaluating quality

This second type of activity builds on the previous one. Inevitably, when producing a product, the question comes up: Have we produced the product with good enough quality? Or perhaps consumers might like to know how to compare different products. Typical authentic practices can be found in laboratories in which products are analyzed. For example, the products can be food products, typically analyzed in specialized food agencies such as the US Food and Drug Administration (FDA). The analysis is directed to components that are, or are not, allowed in the product above a certain concentration. Quality is related to a norm, usually set by a legal system. Materials and substances then occur with a specific composition. Therefore, quality determination consists of distinguishing different components and quantifying these (PV1, 2 & 3; Table 1). For example, the legal norm for drinking water allows a maximum of 250 mg of chloride in 1 liter of water (World Health Organization, 1996). Discussing quality with students also requires the development of the notion of pure: What is pure, and what are impurities? This practical approach can provide students with a motive for why to learn about pure substances and mixtures (see view of science, Table 5).

Table 5. Views of science, the learner, the teacher, and society in Roberts' curriculum emphasis of Science, Technology and Decisions

Curriculum emphasis	View of science	View of the learner	View of the teacher	View of society
Science, technology and decisions	An expression of the wish to control the environment and ourselves, intimately related to technology and increasingly related to very significant societal issues	Needs to become an intelligent, willing decision maker, who understands the scientific basis for technology, and the practical basis for defensible decisions	One who develops both knowledge of and commitment to the complex inter-relationships among science, technology, and decisions	Society needs to keep form destroying itself by developing in the general public (and the scientists as well) a sophisticated, operational view of the way decisions are made about science-based societal problems

Besides learning about composition, the notion of quality involves a legal norm, and raises the questions: Where does the norm come from, who decides it, and why is it decided this way? Should the norm be changed to be stricter (PV11; Table 1)? Related authentic practices may also be dietary practices, in which a consultant advises clients on their diets. This necessitates reading food labels, which motivates a need to understand what are the components that are present in a certain product. Engagement of students in these kinds of practices makes students explore language used by chemists to describe matter (Meijer, Bulte, & Pilot, 2013). Chemical language can still be related to the macroscopic level. However, the first steps of symbolic language may come up, e.g., chloride as Cl^{-}, or nitrate as NO_3^{-}, as indicated on the labels of mineral water.

These types of practices typically are related to *Science, Technology and Decisions* (Table 5). Again, this emphasis has both an individual/personal dimension (view of the learner) and a societal dimension (view of society). For her or his personal life, the student finds it relevant to know what is in the food she or he eats. From a societal point of view, it is of relevance to educate people in the rationale of how norms are decided by a community, and how this involves chemical thinking. This can also provide relevance in the vocational dimension, e.g., for those students who do not continue in an academic career, there is the possibility to be trained as a lab technician. The specific skill development is part of the learning aims.

Assessment of children's growth in sophistication of thinking can occur by presenting students with questions or performance tasks that are consistent with the *Science, Technology and Decisions* emphasis, and that give them opportunities to apply chemistry ideas to the practice of evaluating quality. Performance tasks offer opportunities for controversies in which students have opportunities to consider consequences and apply chemistry knowledge to making decisions. For example, aligned with Kolstø's (2001) "*Science-in-the-making and the role of consensus in science*" and "*scientific models as context-bound*" topics, younger students might be presented with a genuine societal controversy over the best type of storage container for foods, containers made of glass, of wax-coated cardboard, or of different types of plastics. Information could be offered about how various experts disagree, or students could interview respected elders to find out their views and use those as data for consideration in decision-making. Variation will occur as students must decide how the information is relevant to the context they assume. Key to such an assessment is that there is no one right answer; in fact, experts disagree.

The GoKarts assessment template could be used here (see above; Cullipher et al., 2015), and for any of the theme/activity combinations in Table 3. For example, in the Drinking Water unit in Evaluating Quality, students who live in a rural place could be asked to decide what would be the best drinking water for people in a rural town: well water, bottled water, or rain water. This issue has also been extensively studied by Westbroek et al. (2005, 2010). More information could be progressively provided, such as the financial cost of obtaining each type of water, some environmental consequences, health-related risks, and ethical considerations. The teacher could sort students' answers initially along intuitive toward academic by whether water was considered as an object (e.g., the three liquids are fundamentally different because they come from different places – below the earth, from a factory, or from the sky) or more as a mixture consisting of water and some different constituent substances, such as dissolved salts, that depend on what was near the water source. The same assessment could be used at multiple points during a year, or across different years of students' chemistry education. Each student's trajectory from more intuitive toward more academic could be tracked. But more importantly, decisions on how to challenge each student, within the context of the activities in which the student is engaged, could be made based on the student's current level of benefits-costs-risks thinking.

Conceptual designing (synthesis)

The two previously described activities, producing and evaluating quality, can place students in a position such that they experience a need to systematically improve the quality of a product. Then the activity of rational design would raise the production of products beyond a trial-and-error approach. When students become engaged in conceptual design practices, they come to see the relevance of knowing about causal relations between structures and properties. In other words, they develop a notion that *if this particular property is required, then a possible structure may be X* (Meijer, Bulte, & Pilot, 2009; 2013).

With this emphasis, one must distinguish between the practices of material scientists and the practices of chemists. Material scientists deal with designing materials, e.g., superabsorbent materials for diapers, self-healing concrete or composites for aerospace industry. Chemists design components and substances in a design activity that chemists usually refer to as (chemical) synthesis. The underlying reasoning, i.e., chemical thinking, is similar: both invent a substance or a material by purposely designing a certain structure in order that the substance or material should have a specific property, and both analyze whether the property is indeed as desired. If not, this leads to adaptation of the causal relations (PV4 and PV6 in Table 1). Matter has specific characteristic properties due to the arrangement of its specific building blocks (Meijer et al., 2013). In this way, the conceptual designing activity could seed thinking to prepare students to consider future activities. For example, a sub-question of PV4 could be, 'Where, within structures, do reactions occur?' This could apply to synthetic zeolites for drug delivery or to organic molecules often studied in organic chemistry courses in which students learn basic reaction mechanisms such as S_N2 and E1.

With a focus on design, there is also cause to think about benefits, costs and risks for society. Design involves considering desired properties that combine benefits for society – e.g., some products or starting materials are more bio-compatible, stronger, or durable – weighed against costs and risks – e.g., some processes require more energy, some raw materials may be more difficult to obtain than others, or some products are less biodegradable or have reduced possibilities to recycle (such as composite materials). A desired property may even be to increase the likelihood for re-use in a next cycle of production, in which case students are invited to think about the whole production cycle, or fate and transport considerations. In this case, PV11 (Table 1) can be much more elaborated in relation to the other questions posed.

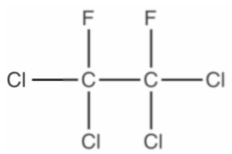
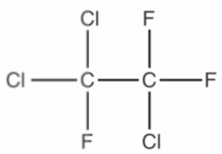
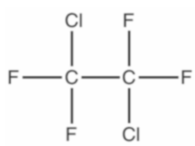
These practices fall within a single emphasis. However, this emphasis is not described by Roberts. It is an emphasis that has elements of *Science, Technology and Decisions*, *Scientific Skill Development* and *Structure of Science*. This emphasis apparently did not show up in Roberts' analysis of textbooks up through 1980, but may be an emphasis that can be related to engineering practices as explicated in recent national framework discussions (e.g., NRC, 2011). Roberts did not intend for the emphases in his review of chemistry texts to be the only emphases that could exist. Thus, inspired by the emphases described by Roberts, this emphasis is defined as *Rational Materials Development*, with 'rational' indicating the need for causal relations, and 'materials development' indicating that this involves matter (materials and substances). In the model of relevance of Stuckey et al. (2013), personal, societal and vocational dimensions for present and future all come into view as shown in Table 6.

Table 6. Views of science, the learner, the teacher, and society in the newly defined curriculum emphasis of Rational Materials Development

Curriculum emphasis	View of science	View of the learner	View of the teacher	View of society
Rational materials development	An expression of the wish to control the environment by developing explicit causal relations about materials with respect to their structures and properties	Needs to become an intelligent person willing to develop the rational basis for chemistry as a techno-science, and its implications for society	One who helps students to understand how causal relations about structure and property form the basis for transforming materials	Society needs technological innovations and acknowledges that investment in attaining this knowledge is key for (economic) survival

Assessment can occur by presenting students with questions or performance tasks that are consistent with the *Rational Materials Development* emphasis, with opportunities to apply chemistry ideas to the practice of conceptual designing (or synthesis). Students could be presented with substances that differ by both explicit and implicit compositional and structural features, and could be asked to argue for which substance might provide desired properties. They could then be asked to propose the structure of a substance that would have an even greater (or lesser) extent of a particular desirable (or undesirable) property. Assessments could be deliberately chosen so that later connections could be made to controversial issues that would engender benefits-costs-risks thinking. For example, Figure 1 shows a possible assessment question. Explicit compositional features include the numbers of chlorine and fluorine atoms in each structure and the number of C-F vs. C-Cl bonds. Students may infer differences in dipole moments of the molecules from the explicit two-dimensional structures as shown, or they may infer relative strengths of van der Waals forces based on implicit differences in molar masses.

Below are the chemical formulas, Lewis structures, and normal boiling points of three common CFCs that were manufactured by Dupont.

Dupont name	Freon-112	Freon-113	Freon-114
IUPAC name	tetrachloro-1,2-difluoroethane	1,1,2-trichlorotrifluoroethane	1,2-dichloro-1,1,2,2-tetrafluoroethane
Chemical formula	$CFCl_2CFCl_2$	$CFCl_2CF_2Cl$	CF_2ClCF_2Cl
Lewis structure			
Normal boiling point (°C)	91.5	47.7	3.8

- Aerosol propellants must be liquids under high pressure, and then change phase to gases quickly when the pressure is reduced to normal atmospheric pressure when the liquid is sprayed. Which of these three CFCs would function the best as an aerosol propellant when mixed with paint and placed in a can of spray paint? Explain why.
- Design a new molecule of Freon that would be an even better aerosol propellant than any of the three Freon molecules above. Draw the structure of the molecule below. Explain why it would be better.

Figure 1. Example assessment within the Rational Materials Development emphasis and the practice of Conceptual Designing

Students' levels of conceptual sophistication are often embedded in the structures of their arguments. For example, Cullipher et al. (2012) presented undergraduate students with a case study that required consideration of health, financial, and environmental consequences in evaluation of refrigerant options. Participants were introduced to a scenario in which an air conditioner manufacturer was trying to determine the best choice of a compound for use as a refrigerant, sulfur dioxide, a hydrochlorofluorocarbon, or a hydrofluorinated ether. Data on pros and cons of each compound were provided in such a way that several decision Regardless of the path chosen, reasoning patterns followed a consistent pattern: Compound [X] is [best/worst] because [primary factor] is the most important [risk/benefit] because [primary factor reason]. The [secondary factor], which is a [risk/benefit], must also be taken into consideration, but is not as important as [primary factor] because [secondary factor reason]. The tradeoff is [tradeoff reason]. A less elaborated response from one participant did not include argument about tradeoffs: "*HFE7100 [the hydrofluorinated ether] is my clear choice in this decision, as hydrofluorinated ethers are known to not harm the ozone layer nor humans nearly as much as the other two options.*" A more elaborated response from a different participant discussed primary and secondary factors, as well as a tradeoff: "*I chose HCFC [the hydrochlorofluorocarbon] mostly because there have been a lot of studies and there is a lot of information. There are some impacts on the environment, but it has no impact on human health. It is a little more costly than SO_2, but it is worth it especially if you are dealing with lawsuits if someone becomes sick or harmed by it.*"

Researching and inquiry

The last type of activity has probably the most elaborate and abstract emphasis, since the intended outcome of research practices is theoretical knowledge. These authentic social practices are typically found in academic research groups at universities and research institutes, where scientists examine questions around such concerns as reaction mechanisms for catalysis, gene-expression in living cells, or the pharmaco-kinetics of drugs.

To have students engaged in the practice of researching with its typical theoretical outcomes as developing models requires prior development in more practically focused activities as described in the previous emphases. Research practices can be within the students' zone of proximal development only if students have experienced a need for developing theoretical models. This need may arise from the previous activity 'designing', since certain causal relation between structures and properties may be missing in the body of chemical knowledge. Then involvement in the generation of models and modeling about structure and property becomes relevant, and questions such as elaborated in PV4, PV5, PV7 and PV8 (Table 1) can be induced. The typical curriculum emphasis relates to students' understanding of the tentative nature of scientific knowledge (view of science and view of society, Table 7).

Again, assessment of students' growth in sophistication of thinking can occur by presenting students with questions or performance tasks that are consistent with the *Structure of Science* emphasis, and that give them opportunities to apply chemistry ideas to the practice of researching and inquiry. This is a common occurrence in many chemistry curricula, thus many good questions and performance tasks already have been developed in laboratory experiments and text book examples. Additional options could be developed from Kolstø's topics. For example, Kolstø's topic "demands for underpinning evidence" could be used as a jumping-off point for generating questions or performance tasks. Taking an example from Kolstø's paper, students could be asked to evaluate the likelihood of a claim that acid rain in Canada results from the exhaust from power plants in the Ohio Valley in the United States, and whether regulation efforts resulting from the Clean Air Act in the United States have had an effect in reducing the acid rain in Canada. To do so, students might consider ways that power plant emissions can be curbed, or they might be asked to reason about data on different types of scrubbers used in smoke stack exhausts of power plants to remove sulfur oxides. Or, they could be asked to determine what types of solutes might be best to use in a wet scrubber solution. The main issue here is to really understand what scientific evidence means, and how scientific modelling underpins scientific claims, as is the case in the climate change debate.

Table 7. Views of science, the learner, the teacher, and society curriculum emphasis of Structure of Science

Curriculum emphasis	View of science	View of the learner	View of the teacher	View of society
Structure of science	A conceptual system for explaining naturally occurring [and manmade] objects and events, which is cumulative and self-correcting	One who needs an accurate understanding of how this powerful conceptual system works	Comfortably analyses the subject matter as a conceptual system, understands it as such, and sees the viewpoint as important	Society needs elite, philosophically informed scientists who really understand how that conceptual system works

Implications of this outline

The outline above is presented very generally. This sequence gives some guidelines and suggestions. For teachers, each of the emphases highlights slightly different roles which give different meta-communications about the relevance of chemistry (science). For curriculum developers and designers of teaching materials (including teachers), our suggestion is not to put too much within one teaching unit. Rather, it is important to make a clear choice of the practices. Some aspects of this outline are more critical, and other parts are more flexible. The order of producing first, followed by evaluating quality, is important because an emphasis of coping generates a need for making decisions that rely on science and technology. However, after one iteration of producing → evaluating quality, there may be motives to return to both again in a more or less cyclic manner. This depends on the preferences of the teachers, and the specific needs of the schools and students. In balancing the emphases, teachers may place more weight on some emphases and less on others. For example, more emphasis may be placed on *Science, Technology and Decisions* during compulsory education, or more emphasis may be placed on *Structure of Science* in university education.

CONCLUSION

The co-development of instructional approaches and assessment provides the means for chemistry educators to make decisions about what is worth teaching in chemistry, and what is not. Emphasis is determined by the choices of practice and activity. Much of the meaning in learning is conveyed through curricular emphases that are messages conveyed by the choices of the contexts in which learning and assessment take place. Different emphases confer different views of the learner, the teacher, science, and society. Chemical thinking is applying chemistry knowledge to considering our own lived worlds, and the capacity for chemical thinking enriches students' views of the worlds in which they live. This was illustrated for benefits-costs-risks thinking, as this focus is often not part of formal chemistry education. Through these illustrations, it is apparent that chemical thinking has relevance for now and the future, for individuals and their vocations and the societies they inhabit, and it has meaning both intrinsically and extrinsically.

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5. EPISTEMIC RELEVANCE AND LEARNING CHEMISTRY IN AN ACADEMIC CONTEXT

It is often claimed that presenting chemical ideas in the context of learning about topics such as fuels, food production, or clothing and fabrics makes the subject more relevant to our learners. This chapter looks to make the case for a completely different kind of relevance: that students should learn conceptual and theoretical content in the context of appreciating the chemical questions that motivated it. Chemical ideas – constructs, theories, models, and so forth – are intellectual solutions that have been motivated by the challenge of developing satisfactory scientific explanations for chemical phenomena. It is the phenomena that provide the epistemic relevance for teaching the ideas. Context-based approaches may seem less abstract to students who struggle with the theoretical content of 'traditional' courses, yet these approaches may not always offer sufficient intellectual challenge to learners with the greatest potential in the subject. Moreover, a core aim of education is to support the development of the whole person, including their intellectual development. Chemistry as an academic subject, by its very nature, provides considerable opportunity to support learners in developing the kind of sophisticated thinking considered to represent intellectual maturity. For many learners, then, the very things that make chemistry a challenging subject (the abstract nature of its concepts and its dense theoretical content) offer particular relevance in the context of wider educational aims.

PREAMBLE: THE CHALLENGE OF ACADEMIC CHEMISTRY

Many students find chemistry a challenging and difficult subject at school and college levels (Danili & Reid, 2004). A consequence of this is that students may readily lose interest in the subject and be less likely to select it as an option unless they can see good reason to persevere with it. Some students are fascinated by chemistry, and some others recognise its value in relation to entering particular careers and professions. However, the relevance of what we teach in chemistry is not always obvious to students, and when a subject is both hard work and does not seem linked to any personal goals, we can understand why so many students either give up the subject, or at least give up on fully understanding it.

There are several reasons why traditional chemistry courses may seem difficult for many students, and three key features are considered here: diversity, extent, and abstractness. Chemistry is a varied discipline and whilst academic chemists may

I. Eilks & A. Hofstein (Eds.), Relevant Chemistry Education – From Theory to Practice, 79–100.

specialise the student is expected to demonstrate competence across a range of different kinds of skills. This does not just include different kinds of lab-work as opposed to theory, but indeed the main branches of chemistry have their own characters. Physical chemistry blends into physics in places, where the same could certainly not be said of organic chemistry that in places morphs into biochemistry.

In terms of the extent of chemistry, there is potentially a lot to find out about. Indeed some traditional chemistry courses included surveys within both organic and inorganic chemistry. Students can learn about the chemistry of the alkali metals, the alkaline earths, and so on. This can include physical and chemical properties. They can learn about analytical tests to identify the presence of various ions. They can also learn about alcohols, and ketones, and ethers, and alkenes, and so forth. This can include synthetic routes to, and typical reactions of, different groups of compounds. Reactions can include those that can be used to identify functional groups, and important 'named' reactions. Indeed the amount of chemistry that could potentially be learnt is immense, and is growing all the time.

Modern courses have moved away from the teaching chemistry as an apparently never-ending survey of things to be learnt, to focus on the key ideas and models that have explanatory value within the discipline. This gives a better flavour of chemistry as a modern science, rather than as a form of natural history. However, this requires students to meet and cope with many abstract theoretical ideas such as oxidation and oxidation numbers; electronegativity and polarity; orbital hybridisation and hyperconjugation; adiabatic changes and entropy; 'good' leaving groups and nucleophiles; and so on.

These various concepts have been adopted at different times by chemists because they have been found useful in developing explanations of chemical phenomena, and so to help bring some order to the otherwise unmanageably vast catalogue of chemical knowledge reported in the subject. A historical perspective helps to understand why, for example, there are alternative and not entirely consistent definitions of oxidation or acid presented in chemistry courses, something that many students find unhelpful if not bewildering.

This abstract conceptual material includes many models, and in particular structural models that often relate to a submicroscopic scale that is not directly observable (Johnstone, 1982; Taber, 2013b). Often these models have limited ranges of application, or need to be used in complementary ways to explain the range of data available (De Jong & Taber, 2014), and indeed models used in teaching may be anachronistic historic models or hybrids of models that were originally distinct within the discipline itself (Justi & Gilbert, 2000). Again the impression that they are being taught one 'wrong' idea only for it to be replaced by another is frustrating to students if they do not appreciate the nature of and motivation for these different models.

Whilst the various abstractions students are taught certainly have relevance to (the current practice of, or at least the historical development of) the discipline of chemistry, many students may struggle to appreciate why they should wish to know about Brønsted-Lowry bases, d-level splitting, or antiaromaticity. The question of the relevance of what is taught is therefore an important one.

THE NOTION(S) OF RELEVANCE

It seems unlikely that there was ever a time when relevance was not *in some sense* a consideration in curriculum planning (Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013). Curriculum should start from aims: what the curriculum is intended to achieve. The curriculum programme is then designed accordingly, and teaching schemes should also be planned with those aims in mind. Teaching and learning activities should then be designed to be relevant to the curricular aims.

The aims of science education have shifted over time – or at least the priorities among multiple aims change. Certainly at school level, vocational purposes – preparing learners for further education and workplace needs – have come to be seen as no more important than supporting the development of scientific literacy or civic engagement (Millar & Osborne, 1998). 'Science for all' has become a common slogan. The question of what science, or more specifically what chemistry, will be useful to the future citizen-as-consumer, citizen-as-activist, citizen-as-voter, etc. becomes just as important as asking what chemistry it is useful to teach at one level (say high school) to prepare those students who may aspire to study the subject at some higher level (e.g. as an undergraduate).

Chemistry as a curriculum subject

We might consider why we teach chemistry in school and university. There is a range of possible reasons. One type of rationale is economic. Chemistry has undoubtedly been of great importance in the development of modern societies in supporting the production of materials for a wide range of purposes. No area of modern life is untouched by the products of the chemical industry and ultimately the research chemist – and we are surrounded by materials that have either been processed to extract and purify them from their 'natural' state or indeed have been manufactured from other materials. This often involves the production of new chemical substances, including many that probably only exist as a result of the synthetic work of chemists and would not otherwise be found in the universe.

Increasing environmental and ecological awareness has led to chemistry being considered, *inter alia*, as one cause of extensive pollution and environmental damage. Yet this only leads to a greater impetus for chemical research and development to find more efficient production processes that have better yields and require less fuel stocks; to replace toxic or harmful ingredients and components; to provide more effective fuel cells; to develop materials with longer useful lives, and shorter afterlives as junk before decomposing harmfully; to find materials that can be used to remove or neutralise existing pollution, and so on. Chemistry as a school and college subject remains highly relevant to societal needs (Burmeister, Rauch, & Eilks, 2012; Eilks & Rauch, 2012).

However there is a less pragmatic way to understand the curriculum which looks less to societal needs than to the development and formation of the person (Hansen & Olson, 1996). Two somewhat different perspectives may be considered here. One approach is to consider first what skills and qualities we desire in fully formed people, and then how education can support personal growth towards that ideal. Curriculum subjects can contribute by providing opportunities for learners to develop in different ways. The study of sciences, for example, has been considered to contribute to the development of logical patterns of thought and of creative problem-solving skills (Stuckey et al., 2013).

A somewhat different starting point considers the nature of what it is to be human in terms of forms of our culture. Human culture encompasses arts and sports and sciences and politics and so forth – and so a liberal education should provide the learner with access to these important aspects of the culture. The sciences are among the greatest achievements of human culture and every learner should be given the opportunity to understand and appreciate something of key scientific achievements (Snow, 1998). To be a cultured person in the twenty-first century, one needs to understand something of the nature of science.

These different perspectives can be seen as complementary: a person can be educated for enculturation *and* personal growth *and* still develop knowledge and skills that equip her/him to take up a valued place in the economic system of her/his society. However, these different perspectives have different emphases and priorities and so there are tensions between them when making choices about the specific subjects and topics that are included in a curriculum, and in the kinds of learning activities that are most educative.

Changing priorities for structuring chemistry teaching

The organisation of chemistry teaching has been influenced by various perspectives deriving from different strands of educational thinking. Figure 1 caricatures some of the changes that have been seen in thinking about the chemistry curriculum over a period of some decades.

One area of academic focus on chemistry teaching has concerned the nature and structure of the disciplinary material itself. In particular, researchers considered the internal structure of the concepts that might be taught in chemistry with a view to offering a logical analysis. Concept analysis included identifying pre-requisite concepts that needed to be taught earlier in the curriculum before other concepts that (according to the internal logic of the subject) necessarily drew upon them (Herron, Cantu, Ward, & Srinivasan, 1977). This approach puts a focus on the hierarchical structure of concepts. So the concept of covalent bonding can be subsumed under the overarching concept of chemical bonding, and ketones can be classed under carbonyl compounds, etc. Chemistry presents particular challenges in the way that some of its most core concepts – substance, reaction/chemical change – are difficult for students to fully appreciate, and tend to be acquired over extended periods (Taber, 2012). Therefore, although conceptual analysis informs a ‘logical’ presentation of material, this often has to be taught through a spiral curriculum where ideas are revisited over time (Bruner, 1960). Despite this need for some ‘boot-strapping’ between key concepts, conceptual structure undoubtedly remains an important consideration when selecting and organising material to be taught in chemistry. For material to be relevant to learners it has to be sequenced in terms of necessary prior learning.

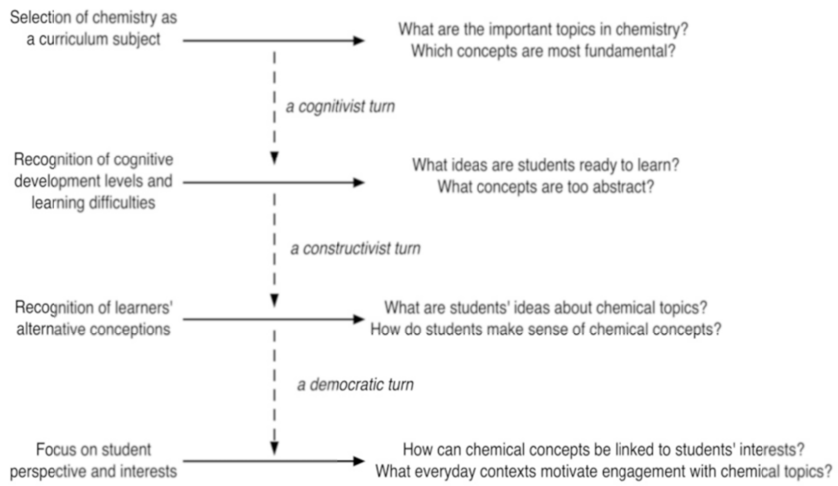

Figure 1. Shifts in focus on course design

Learning difficulties experienced by many students when taught chemistry suggest that content analysis to determine a logical order of presentation might be a necessary, but is not a sufficient, condition for effective instruction. In particular the influence of work in the Piagetian tradition suggested that there were inherent limitations in children's and young people's cognition (Bliss, 1995; Piaget, 1970/1972). According to Piaget's model of cognitive development people normally only become able to undertake the kind of thinking needed for much scientific work – being able to mentipulate abstract ideas in mind, operating on them as mental objects – during adolescence. This research programme suggested that much of the science included in secondary level school curriculum was likely to be inaccessible to many of the students being taught as they would not have fully acquired (what is termed) the level of 'formal operations' (Shayer & Adey, 1981).

Of course neither the Piagetian model, nor its consequences were universally accepted. Followers of Jerome Bruner (who claimed that any child of any age could be taught any topic in an intellectually honest manner) would argue that the findings from Piagetian research should not exclude abstract science concepts, but rather illustrated the pedagogic challenge of presenting such concepts in sufficiently concrete ways for learners to make sense of them. Whichever view was taken, there was something of a 'cognitivist turn' in considering curriculum design that reminded planners that the nature of cognition was as important as the nature of subject matter in thinking about setting out target knowledge for students. This offers a new slant on relevance: for material to be relevant to learners it has to be accessible to them through their existing cognitive apparatus. So, for example, lasers in everyday devices (CD or DVD players, computer drives) may offer a context for teaching about quantum theory that might interest many primary school children, but arguably it may not be relevant in terms of what they are in a position to make good sense of.

Consideration of the cognitive 'architecture' supporting learning and the nature of learning processes informed the increasing influence of 'constructivist' thinking about learning (Osborne & Wittrock, 1985), and with it work to explore students' thinking in science topics (Driver, 1989; Gilbert, Osborne, & Fensham, 1982). If learning is understood as an active process of interpretation and making sense of sensory input in terms of existing conceptual resources, then effective teaching has to engage with existing understanding. There was something of an explosion of interest in exploring student understanding of various phenomena and concepts relevant to science learning. The research literature offers many accounts of children's and other learners' ideas, misunderstanding, conceptions, mental models and intuitive theories (and various other descriptors are also used) related to acids, the behaviour of gases, chemical bonding, rates of reactions, orbitals, and so forth (Duit, 2009). So there was something of a constructivist turn in thinking about curriculum and pedagogy. For subject matter to be relevant it not only has to be scheduled into teaching schemes in accord with its logical structural relationship with other subject matter and needs to be presented in a form accessible to learners at that stage of development, but it also has to be interpretable in turns of the learners' existing knowledge and understanding. The term 'knowledge' is not used here in its limited philosophical sense of necessarily being 'true justified belief' but rather in a wider sense of what someone either believes to be the case or considers as a viable possibility (Taber, 2013a).

Ausubel (2000) saw meaningful learning as occurring when presented material was both potentially relatable to a learner's cognitive structure, and actually was interpreted by the learner through that existing structure. From this perspective relevance could be related to *potential* meaningfulness. For material to be relevant to learners it has to be relatable to some aspect of their existing conceptual structures for making sense of the world. It should be noted however that meaningful learning is not necessarily the learning intended or desired by the teacher (Taber, 2014). The canon of constructivist studies offer a good deal of evidence that meaningful learning – making sense of teaching in terms of existing understanding – only sometimes leads to an understanding comparable with canonical target knowledge (Gilbert & Watts, 1983; Taber, 2009).

It is possible then to argue for the relevance of teaching in terms of disciplinary structure, in terms of accessibility in relation to the cognitive demands made on learners, or in terms of being potentially meaningful by being relatable to learners' prior learning (what they have actually learnt, rather than just which prerequisite ideas they have been exposed to in instruction). Discussions of relevance in chemistry teaching have however come to be increasingly seen to be about engagement and motivation through linking with students' interests (Osborne & Collins, 2001; Pintrich, Marx, & Boyle, 1993). We might consider this a 'democratic' turn in thinking about curriculum content and how to present it, because it is now widely seen as unreasonable to expect learners to find something relevant simply because some external authority decides it should be taught. Perhaps for some this is a principled shift, related to the student voice movement which argues that learners should have input into decisions about their education, including aspects of curriculum, assessment, and teaching approaches (Jenkins, 2006). For others, this may be a more pragmatic consideration having perhaps concluded that it is not much fun teaching a wonderful and fascinating subject such as chemistry to a class who are only fascinated by how to avoid doing any work and only wonder about how long they have left till the end of the lesson.

RELEVANCE IN TERMS OF STUDENT INTERESTS

In this approach, topics, projects or examples are chosen not just because they are relevant to chemistry as a subject (and suitably structured, accessible to the students' cognitive level, and potentially meaningful in terms of prior learning), but because they will interest learners, who will see their relevance beyond the curriculum. So teachers look to link curriculum topics to learners' extra-curricular interests and activities both because this will be appreciated by learners, and because this will motivate and engage them by triggering interest in the subject matter. From this perspective, for material to be relevant to learners it has to be seen by the learners as offering them greater knowledge or skills in a domain of personal interest. Working from this perspective clearly requires knowledge of students' actual interests and not simply assuming that pupils will be interested in domestic appliances because they are familiar from and useful in the home (Jones & Kirk, 1990). Moreover, having an interest in something does not necessarily motivate learning more about it, at least not in technical terms. Our interests may be pragmatic. A chemistry teacher may be fascinated by how chocolate manufactures provide a product that 'melts in the mouth' and has a pleasing texture. Many chocolate lovers are simply happy enough that chocolatiers have specialist skills and would not enjoy chocolate any more for understanding its manufacture.

Despite this proviso, there is certainly a valid educational argument here. Before students can learn they need to be attentive to what is being taught. Much we wish to teach in chemistry is abstract and complex, and chemical principles often seem counter-intuitive. Conceptual change has been found to be something that is often hard-won, by scientists as well as novice learners, and relies upon extended (mental) engagement with ideas (Vosniadou, 2008). Ideally we want learners to be in a 'flow' experience where they are engrossed with their work to the exclusion of other distractions (Csikszentmihalyi, 1988) – something that is not typical of learners' experiences in many classrooms and lecture theatres. The starting point, then, is to get students interested in what we are to teach, to provide a 'hook' to pique their interest, and then draw them into chemistry content through its relevance to that initial issue, question or context that they already consider to be of interest and worthy of their engagement.

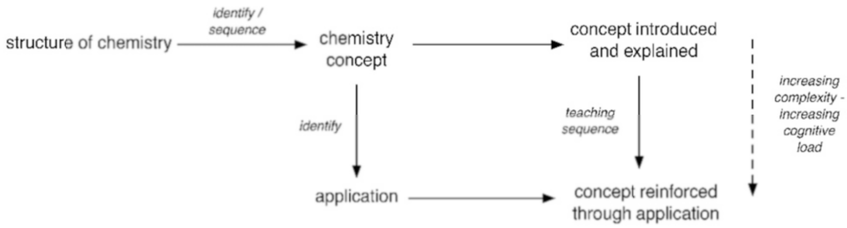

Figure 2. Applications introduced to reinforce teaching of chemical concepts

Re-ordering the presentation of concepts and applications

This approach to some extent reverses the logic of organising teaching *within* a topic. Traditionally (Figure 2) applications of chemical concepts may be discussed after teaching about the concepts themselves. The argument is that students need to understand the concept before they can appreciate how it might be applied. Moreover, from the cognitivist perspective it is important not to overload learners' working memory by asking them to mentipulate too much information in mind at any one time (Baddeley, 2003). From this perspective it is best to teach the concepts, and then once they are well understood, show how they can be applied in various contexts to reinforce and help consolidate understanding of the concepts themselves (Taber, 2013a). In this approach, the topic is selected based on the structure of chemistry as a discipline, and applications are then selected to fit the concepts being taught. So, for example, after considering the nature of chemical equilibrium, the example of the industrial binary synthesis of ammonia might be chosen as one context in which the concept is useful.

A different logic is employed in teaching approaches that start, not from the concept itself, but from discussion of some context where the chemical concept is important. This approach is seen with teaching and learning of chemistry (and other science subjects) through context-based courses. The argument here is that the more traditional approach of explaining the science concepts, and then presenting applications to show how these ideas are applied should be reversed (Figure 3).

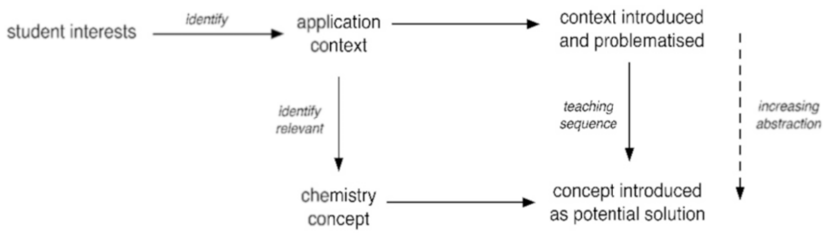

Figure 3. Applications introduced to motivate the learning of chemical concepts

The traditional approach considers cognitive factors: students first have to understand the basic principles, and then they will be in a position to see how they are applied in diverse applications. Logically they cannot make sense of the particular application of the idea until after they understand the basic general principle they are being asked to conceptualise in that specific context. How can a learner apply principles of chemical equilibrium to the Haber process, before they have been taught and developed a clear understanding of what those principles are?

Context-based approaches derive from the view that the traditional approach considers the cognitive aspects of learning, but that these are irrelevant if the learner is not motivated to engage in the required cognition. Students, especially younger or less motivated students, it is argued, will not be engaged enough during the presentation of the science to get to the point where they can appreciate the applications. Rather, the logic goes, we should engage students through the presentation of an issue or problem that they can see the relevance of, and then use that as a hook to interest them in some science that may be useful in addressing that issue or problem. From the learner perspective, it is argued, we should start from something that already interests the learner, problematise it, and then show how science explains or offers solutions by introducing the core concepts as they are needed along the way (Figure 3). After all, for most people science is valued for its utility value, rather than developing knowledge for its own sake, so in teaching most learners will be more impressed by how science enables us to do things people want to do rather than because it offers a largely consistent conceptual framework for understanding the world.

An issue that needs to be considered in context-based teaching is that raised by research which suggests student thinking is influenced by context – that the ideas brought to mind in a particular topic area may be quite different depending upon the context in which they are presented (Engel, Clough, & Driver, 1986; Mestre, Thaden-Koch, Dufresne, & Gerace, 2004). However, this applies to academic as well as everyday contexts (Taber, 2000; Teichert, Tien, Anthony, & Rickey, 2008), and might be considered more of a challenge than a problem *per se*. It does however suggest that studying an abstract concept within a particular context offers no assurance of generalisation later to other contexts. This raises the question (perhaps for empirical study) of whether context-led approaches to teaching chemical concepts could shift issues of near-transfer of learning to become more akin to far-transfer (Gilbert, Bulte, & Pilot, 2010; Hammer, Elby, Scherr, & Redish, 2005) if the student perception is less of being asked to apply a familiar concept to an unfamiliar example than being asked about a completely different topic (i.e. context) than that studied.

A recognised problem of context-based teaching is that of designing contexts that both interest students and do motivate the need for the concepts we feel it important to teach. Identifying particular contexts that work as good hooks for particular groups of students is certainly possible (e.g., Stuckey & Eilks, 2014, see also the discussion of Table 1 in the chapter by Sjöström et al. in this book). However, designing a set of contexts that both genuinely links to students' interests and collectively allows us to teach the full range of concepts we would like to include in the chemistry curriculum may be more difficult. The teaching of conventional concept areas may need to be split across several different contexts (which may offer useful opportunities for review and reinforcement of some ideas, but may also lead to fragmentation of concept areas across the course). The order in which learners meet concepts may require considerable compromises on the kind of 'logical' sequencing that would derive from the conceptual analysis of the discipline itself. Adherents of the context-based approach would argue that any losses in terms of teaching according to the internal logic of the subject are more than outweighed by the increase in student motivation and engagement. This may explain why studies seem to show that generally learners attain similar levels of understanding in context-based courses as in more traditional approaches despite any compromises in terms of disciplinary structure (Bennett, Hogarth, & Lubben, 2003).

CHANGING PRIORITIES IN TEACHING CHEMISTRY

As well as the move to teach chemistry concepts through contexts, related to thinking about student motivation and engagement, the teaching of chemistry also responds to changing views about the relative importance of different curriculum aims. One example might be the recognition that it is important for all citizens to understand about environmental issues, and the role that 'green chemistry' can play in contributing to a less polluted and more energy-efficient world (Emsley, 2010, see also Chapters 9 and 14 by Sjöström et al. and Bodner in this book).

Another example might be the increased recognition of the potential of inquiry-based teaching and learning and the importance of offering learners authentic experience of scientific enquiry as a context for developing their enquiry skills (Alsop & Bowen, 2009; Lawson, 2010; Taber, 2011a). Experience of formally assessed 'investigations' in secondary science in the English context (Jenkins, 2000) became little more than exercises in following instructions in how to score marks given the high status of the outcomes (for students, teachers and schools). Even when students followed through on the full inquiry cycle in one assessment, there was little clear value in 'investigating' such issues as how reaction rate varied with the concentration of acid or temperature of a solution when all the students would already be aware of the expected results. Such 'investigations' were relevant to assessment schemes, but had little relevance to scientific inquiry, to learning authentic enquiry skills, or indeed to any questions that the students might genuinely be looking for an answer to.

Risking losing the baby: Relevance as a contended notion

It seems then that there are different possible notions of what we might mean by relevance in chemistry education (Stuckey et al., 2013), each likely to inform the selection, sequencing and presentation of materials in different ways (Figure 4). These different considerations are not always necessarily in opposition to each other, but they do present different priorities and this can lead to tensions in making judgements about the planning of teaching. There is a saying to 'throw out the baby with the bath water' meaning to make changes that lose what is valued in the current situation as well as what is considered to need replacing. There is a danger when shifting from judging relevance in terms of discipline and conceptual structure to considering relevance in terms of student interests that one might lose the coherence and central chemical character of a course in order to jettison an approach judged not to sufficiently engage learners.

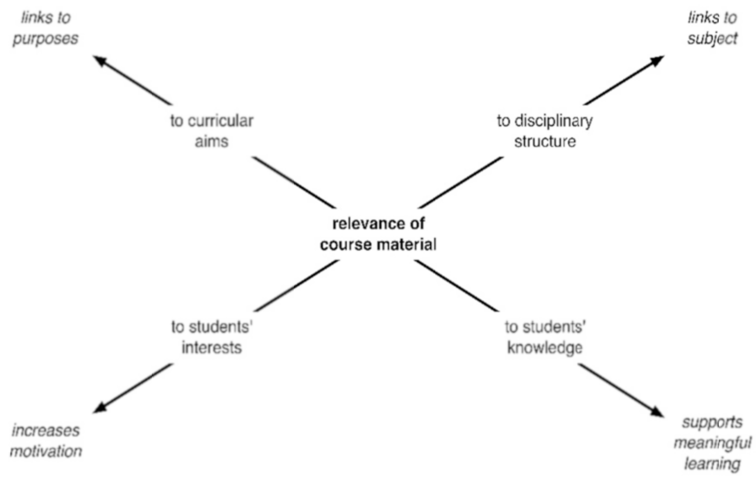

Figure 4. Different forms of relevance

Similarly, a shift from judging relevance in terms of the structure of chemistry to considering relevance to societal issues also brings risks. Science educators have strongly argued for science education that develops an understanding of the way science impacts upon society, is channelled by societal pressures, and feeds into discussion of key issues faced by communities (Sadler, 2011; Sadler & Zeidler, 2009). Here our curricular aims, our purposes, may be as much about understanding science in society and the politics of science and the way science is used and abused in politics, as about understanding scientific concepts. Arguably such an understanding is at least as important for future citizens as understanding the concepts themselves (Jenkins, 1999, see also Chapter 10 by Belova et al. in this book). What is clear however is that class time and teacher input (into planning, into developing materials, into supporting learners) are finite and limited resources: and prioritising teaching about science in social contexts inevitably puts less emphasis on the science itself. Indeed, to use the English context as an example again, the decision to reduce the prescribed subject (i.e. science) content in the National Curriculum to allow more time for broader educational aims related to science for citizenship (QCA, 2007a, 2007b) led to a strong campaign of criticism that characterised the revised curriculum as only being fit to support discussion of science at the level found in the pub (i.e. public house, a place for social conversation and drinking), and not suitable as a genuine science education (Perks, 2006). Whilst such criticisms can sometimes fail to acknowledge the significance of important broad aims of science education they do remind us that greater relevance to the needs of the learner as future citizen may – just as prioritising a focus on the relevance of teaching and learning to students' current interests – require some compromise on the relevance of teaching and learning to the internal logic and structures of the science disciplines.

THE NEEDS OF THE FEW?

Sometimes the questions raised here are framed in terms of the needs of the many versus the needs of the few. A minority of students will select chemistry as a post-compulsory subject. Quite a small proportion of the school population will choose to specialise in chemistry and undertake degree studies to become a chemist, and then go on to work professionally as chemists. Perhaps, it may be argued, this few would make better progress if chemistry teaching was structured primarily in accord with the logic of the subject. However, these are not only a small fraction of the population, but they are going to be among the more capable learners, who will surely cope with a slightly less coherent path to expertise. It seems to make little sense to design a curriculum for all learners primarily in terms of the needs of this small group.

The assumptions behind this argument might be characterised as:

- Most students benefit greatly from a curriculum which compromises the structural coherence of the discipline in order to either (a) prioritise student engagement with learning; and/or (b) emphasise science for citizenship over science for its own sake;
- The main advantage of prioritising disciplinary relevance within curriculum design is to support the learning of those few who will go on to specialise in the subject, and this requires putting the interests of this small group over the needs of the wider cohort;
- Any losses in terms of limiting the progress of the few in coming to better understand the conceptual content and structure of chemistry can be readily made up once those individuals enter specialist courses at university level.

The present chapter derives from a perspective that recognises some strengths in this position – but also some important weaknesses. There is certainly an argument that the needs of the most able learners are not always being met when the disciplinary structure of a subject is down played, but what is easily missed is the potential value of *disciplinary relevance* to learners in general. That is, we may indeed be in danger of discarding a baby that needs nurturing as we empty out its dirty bathwater.

The needs of the gifted learners

Various terms are used to describe students who show particular ability and aptitude in academic areas. Here I am using the term ‘gifted’, although I am aware that has unfortunate connotations (of something inborn, fixed) for some people. Alternative terms include the highly able or the talented. The area of gifted education is complex, and there is no clear consensus on important questions such as what is meant by gifted; how best to identify gifted learners; how broad such gifts need to be to deserve special attention in education; and what kind of special provision, if any, is appropriate for gifted learners (Taber, 2007). Whilst gifted education is a major issue in some educational contexts, there has been a rather modest focus on gifted education within the scholarly literature in science education or chemistry education more specifically.

Despite these provisos, it seems undeniable that students vary considerably in their level of attainment in academic subjects such that a minority of students in any year-cohort are likely to be capable of working at a level that far exceeds what their more typical classmates can currently manage. This can present a major challenge for teachers. Setting (and in-class setting), acceleration, enrichment classes, peer tutoring, differential support, individualised working etc., may all be adopted to some degree in different contexts (NDoE, 1997; Stepanek, 1999).

The gifted are certainly not a discrete category, as attainment, and the abilities that support it, vary on continuous scales. So there is always a demarcation issue of where to ‘draw the line’ between gifted and simply able or highly achieving that may make us cautious in employing labels such as ‘gifted’. Development is not uniform and even – so a student who is seen as gifted at one point in their school career may not seem so especially capable some years earlier or later. Of course, what a person is capable of today depends in part on the developmental experiences, and so opportunities, they have been exposed to. So in societies where opportunities are inevitably unequal due to the reality of impoverished or advantaged upbringing we would expect students from some socio-economic backgrounds to be over-represented among those we might label as gifted.

Moreover, a student who is exceptionally strong at (for example) using mathematics in chemistry may not be exceptional in some other areas of the subject. Some students who appear highly gifted in their oral performance in class may be limited in their written work by modest literacy levels, and there are indeed students sometimes labelled ‘twice exceptional’ who show gifted characteristics in some curriculum contexts whilst also being diagnosed with specific learning difficulties (Winstanley, 2007). Such considerations may also make us wary of labelling students.

However, if we ignore the issue there will be learners in many classes who are not being offered genuine educational opportunities in their lessons. According to Vygotsky’s (1934/1986, 1978) model of development, learners will make progress when they are scaffolded to achieve more than they can currently achieve unaided in their zone of next (or proximal) development. Ignoring the phenomenon of gifted learners will often equate to asking some students to only undertake work that is within their zone of actual development, where they may hone their existing skills and knowledge, but will have few opportunities to move beyond what they can already do.

The challenge of developing post-formal thinking for all students

In common treatments of Piaget's theory of development, the fourth major stage, formal operations, is considered as the highest level of development. It has been considered as necessary for scientific thinking because it enables a person to apply logical thought patterns to abstractions. Not only can the person at formal operational level form abstract representations of objects, but they can treat these 'mental objects' as the subject of further mental operations. This kind of mentipulation is considered characteristic of, and so necessary for, scientific thinking. Indeed science contexts have been presented as suitable for encouraging the development of formal operations among early adolescents, such that 'cognitive acceleration' can result from suitably structured and scaffolded engagement in science learning activities (Adey, 1999; Adey & Shayer, 2002). From this perspective, traditional inductive science learning activities requiring the recognition and testing of abstract patterns in data remain a valuable part of any science curriculum.

However, there are good reasons to think that attaining formal operations is a necessary but not sufficient facility for scientific thinking. For one thing, as Kuhn (1977) pointed out, science proceeds through an essential tension between the convergent thinking associated with testing experimental ideas, and the divergent thinking needed to look beyond existing scientific concepts. Science, even in periods of non-revolutionary 'normal' science (Kuhn, 1996), depends upon creative thinking to generate the ideas that logical thought will operate upon during critique (Taber, 2011b). Moreover, logical thinking is an excellent tool when we have complete, clean data sets that match one or other theoretical possibility, but is limited in responding to fuzzy situations characterised by incomplete information of uncertain quality.

Some scholars have described a 'fifth stage' (Arlin, 1975) of 'post-formal' operations (Kramer, 1983; Sternberg, 2009) that characterises the kind of thinking needed to deal with the complexity and uncertainty often faced in real-world problem solving (and this would include much front-line scientific work that has not been simplified and bowdlerised to make it seem suitable for classroom presentation; as well as many socio-scientific issues). Research suggests that adolescents and even college students do not readily deal well with the complexities of real-life problems (Perry, 1970), and that commonly students respond to the loss of certainty when faced with fuzzy, complex issues by a retreat into relativism. So when there is no clear right answer, then (students decide) all possible answers are equally acceptable and selection is little more than opinion or personal taste (Kuhn, 1999).

This should be a major issue for education, and science education in particular. Science, unlike mathematics, does not claim to produce certain knowledge but rather a provisional form of knowledge that is always open to new evidence and alternative perspectives (Taber, 2008b). Yet we do have criteria for evaluating scientific ideas, such as conceptual coherence (Taber, 2008a), and science offers robust and not just arbitrary knowledge. This is just the kind of complex issue that most (school and even college) students are not ready to fully deal with (Perry, 1970), inviting relativistic judgements:

- If science cannot be absolutely sure, then astronomy is no better than astrology;
- If evolution is 'just' a theory, then it is on par with the ideas of young-earth creationists;
- If scientists cannot all agree on the extent to which climate change is due to anthropocentric inputs into the atmosphere, then we can choose not to believe it, or at least not to worry until scientists get their act together and all agree on what the evidence means.

Arguably one of the key tasks of science education is to help learners understand how science can be both generally reliable yet concerned with producing fundamentally uncertain knowledge (Taber, 2008b) – as this is a key basis for understanding science in the context of citizenship, political debate, social issues and personal decision-making. Science can tell us about the costs, risks and possibilities of nuclear energy, genetic engineering, kidney transplants, recycling waste, rooftop solar panels, hormone replacement therapy, and upgrading our broadband service. Science cannot however tell us what decisions to take about such matters. Research tells us that by the end of schooling many students are able to apply scientific concepts in unambiguous contexts – but are not ready to deal with the uncertainty and patchy information characteristic of the problems and situations typical of much human experience beyond the simplifications of the classroom.

THE DEVELOPMENTAL RELEVANCE OF THEORETICAL CHEMISTRY: COGNITIVE ACCELERATION THROUGH CHEMISTRY EDUCATION

If science education has been shown to be valuable in helping students acquire formal operational thought – then perhaps it also has potential to support development of post-formal thinking as well. Cognitive acceleration through science education (Adey, 1992) has drawn upon contexts where there are physical patterns to be found (such as the principle of moments) by helping students practice the control of variables and fair testing. Perhaps supporting learners in the next stage of development requires similarly carefully scaffolded engagement in working in contexts where patterns are less clear cut, where there are more variables to be considered (not all of which can be controlled at any time), and where data sets may more often be incomplete or imprecise. Rather than leading learners to simple clear preferred conclusions (such as the principle of moments) sometimes learners may have to settle for several complementary models with different preferred ranges of application.

Arguably the social sciences could provide relevant contexts here – and indeed those gifted students who are operating effectively with post-formal thinking whilst still at school may (sadly) find history and social studies more engaging and challenging than the sciences with their tendency to focus on 'right' answers and canonical theories. However, an authentic science education, one that offered insight into science in the making and not just the resulting rhetoric of conclusions (Niaz & Rodriguez, 2000), could certainly hold its own against the social sciences.

Chemistry, in particular, is a discipline that has an extensive set of concepts, principles and theories that provide useful thinking tools, but which lack the law-like nature of so much taught in physics. It has been argued that many ways chemistry is an ideal subject to challenge the most able learners who thrive on the theoretical, and relish having to make sense of complexity (Taber, 2010). This logic can however be extended. All adolescents need to be supported in dealing with uncertainty and complexity without simply retreating into relativism, and accepting that 'anything goes'. The theoretical problems and conceptual tools of chemistry offer just the intellectual challenge that some of the most able are ready for and thrive upon. Many other students will require considerable support in this area – so suitable scaffolding will need to be provided, and then faded as students develop.

Offering epistemological relevance for teaching chemical theory

For many of the most able students, then, the abstract and theoretical nature of chemistry can be a welcome opportunity to stretch themselves intellectually. This aspect of chemistry also offers potential educational experiences that can be of value to all learners in terms of supporting cognitive development, but there remains the problem of theory appearing not only abstract, but also somewhat arbitrary and of little personal relevance. As suggested above, it is this consideration which often leads to a decision to teach through contexts and applications which can motivate the need to introduce particular knowledge, skills, concepts – but may mean that concepts are introduced in isolated ways detached from the disciplinary context.

An alternative approach is to revisit the history of the subject, and consider the original motivation for the creation of the ideas which have become part of the theoretical toolkit of chemistry (cf. Allchin, 2013). Chemical concepts are introduced as a means to help make sense of phenomena studied in the laboratory, and principles and theories are put forward as a means to explain and relate different aspects of phenomena. Every canonical concept started out as a conceptualisation formed by some individual looking to make personal sense of some aspect of chemistry. Science is motivated by awe and wonder, and an epistemic hunger to better understand. Yet planning education in these terms has become tainted as elitist as most young people do not aim to be scientists. However, most young children tend to be 'natural scientists' in terms of their curiosity and drive to explore and make sense of their environment. This suggests that if teaching starts from phenomena, then these naturally motivate a need to label, characterise and explain (see Figure 5).

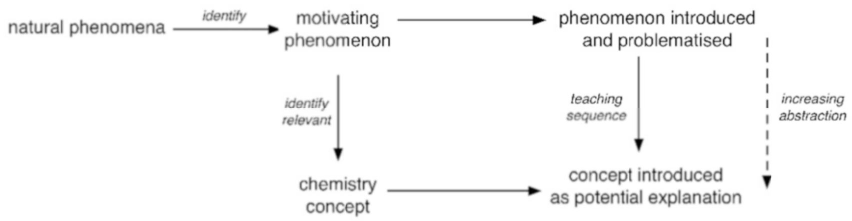

Figure 5. Epistemic relevance for introducing chemical concepts

It is widely found that learners are often fascinated by simple chemical phenomena in lower secondary school, but many become disenchanted as they pass through the school and lessons often become more theoretical. Chemistry as a discipline is certainly highly theoretical, but as a science it develops through the interaction of theory and experiment. Courses that consist of sequences of theoretical topics, with practical work apparently bolted on to teach the theory reverse the logic of the subject, and are not authentic in offering insight into the interplay between theory and experiment at the heart of the discipline. Perhaps a major problem with chemistry teaching is that too often it has short-cut the awe and wonder by moving from bang and smells (attention grabbing, but atheoretical) in introductory classes, to de-contextualised theory (challenging, but lacking relevance) in more advanced grades, sometimes supplemented by practical work designed to meet assessment needs rather than providing experience of the chemistry (Taber, 2008b). Perhaps in part this relates to health and safety concerns, but with the increasing availability of high quality videos of chemical processes to supplement laboratory work students can vicariously experience the toxic and extreme without being exposed to the risk. It would be interesting to see how students responded to a chemistry course designed from the structure of the discipline and based around making sense of chemical phenomena, and that introduced concepts and theories as they were motivated by the need to better make sense of nature itself.

CONCLUSION

This chapter is offered as a warning against incautious enthusiasm for chemistry teaching that is organised around contexts intended to reflect students' own interests regardless of the cost to maintaining other kinds of relevance that are important in curriculum development and lesson planning. Teaching through contexts assumes that students are motivated by everyday contexts that can be presented as applications of chemistry – rather than motivated by an epistemic hunger to make better sense of the natural world. In many cases this may indeed be so – but we should not forget that many young people (and arguably in particular many who are likely to be attracted to science) may be fascinated by the apparent mysteries of natural phenomena and the ideas, concepts, and theories that can allow us to build up models and explanations of our world. These learners may be especially impressed with how science as an enterprise aspires to develop a coherent conceptual framework where new conceptual bricks are expected to fit within the existing edifice – something that may not always be fully recognised by high achieving students (Taber, 2008a) and may be especially hard to appreciate if science subjects are taught in a piece-meal way without strong reference to overarching concepts and disciplinary structure. Perhaps this is not the most pressing consideration when working with some student groups, but it may be very relevant for ('gifted' and other high achieving) learners in some classes.

If we assume that everyday contexts do often motivate student interest then we run into new challenges. We have to identify suitable contexts that both enthuse students and link to the chemistry we feel we should teach. One problem here is that chemistry is a fundamental science about substances and their purification, identification, characterisation and reactions: whereas many suitable applications may offer better contexts for teaching about materials rather than substances. Materials science builds upon chemistry – but as a science needs to be ground upon an existing understanding of chemistry.

Perhaps even more serious in some ways is the question of fairness and equity. If we select chemistry topics for a course in terms of disciplinary relevance, and some students are more interested than others in the chemical phenomena and our associated concepts and explanations, then those who are not engaged are at least basing their disinterest on the nature of the subject. If instead we seek to teach chemistry through topics such as, say, Formula 1 motor racing technology, or fabrics used in the fashion industry, then we are introducing an immediate bias in terms of which students have existing knowledge, and indeed any interest, in that particular topic (Taber, 2003). This criticism is perhaps assuaged if we select contexts recognised to be major socio-cultural issues we would want *all* students to learn about in their own right – energy sources, climate change, environmental protection, quality control in food and medicines – but the problem of fitting issues to a broad and integrated conceptual framework for the subject remains.

The argument here is not that context-based teaching is necessarily a bad thing, and certainly not that the design of all chemistry teaching should be solely or primarily focused on the history and logic of disciplinary structure. Rather the argument is that there are different forms of relevance that need to be taken into account in considering how to make chemistry teaching relevant to learners (Stuckey et al., 2013) and epistemic relevance, and potential to support cognitive development needs to be considered. We have a range of potential curriculum aims, and these might direct us to make different choices with different groups of learners, or at least to adopt a different profile of responses to the different imperatives with different students or groups. If we want science teaching to contribute to the development of the whole person, then some of the more conceptual and theoretical nature of chemistry (with its multiple models) may actually offer a useful basis for supporting the development of post-formal thinking. If we want students to experience something of the awe and wonder that many scientists feel about natural phenomena and the intellectual excitement of science, then organising some teaching to give an authentic flavour of how and why chemical concepts, models and theories are proposed and modified in response to the natural phenomena themselves may provide a valuable form of epistemic relevance. There is a place for context-based teaching, problem-based learning, inquiry-based courses, and various other ways of organising chemistry teaching that might seem more progressive and student-friendly. But if such innovations need to come at the cost of students failing to see any overall disciplinary structure within the diverse chemical ideas they meet, and reversing the logic of scientific development (so starting from existing technology, rather than from the observable natural phenomena that sparks the desire to understand) then the chemical baby might well find itself abandoned with its soiled curricular bathwater.

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DEBORAH CORRIGAN, REBECCA COOPER AND STEPHEN KEAST

6. THE ROLE OF VALUES IN CHEMISTRY EDUCATION

In considering the role of values in chemistry education, there are a number of assumptions made that may not be all that obvious. For example, many people would contend that chemistry (and science) is value-free as it strives to provide an objective view to explain natural phenomena. In a similar vein the idea of values in chemistry education may also be considered value-free, or if there are values associated with chemistry education, are they attributable to only the education aspects. This statement raises the question of how chemistry education is different from chemistry. Additionally, there can be assumptions about what we mean by values and how are they different from beliefs and attitudes. What is also important here is how do values have an impact on learning and teaching, particularly in relation to chemistry. This chapter will explore these issues and assumptions and not only what they mean from a research perspective, but also how we can explore such issues in practice.

INTRODUCTION

There are numerous definitions of values throughout the research literature (Halman, 2010). Such a range of definitions may be due to the nature of values as mental constructs and consequently can never be observed directly by others, but rather can only be inferred based on observation of people's behaviours. Halstead (1996) provides a general definition of values as:

> the principles, fundamental convictions, ideals, standards, or life stances which act as general guides or as points of reference in decision-making or the evaluation of beliefs or actions and which are closely connected to personal integrity and personal identity. (p. 5)

From this definition, Halstead highlights the more enduring and basic nature of values in comparison to beliefs, a form of knowledge that is personally viable for meeting personal goals (Tobin, Tippins, & Gallard, 1994), such as 'I trust what you say', or attitudes, an evaluative response to an object (Eagly & Chaiken, 1993), such as 'I do not like airplanes'. Pajares (1992) points out that terms such as belief are often used to define all mental constructs and others terms such as attitude, values, judgements, perceptions, dispositions and rules of practices, and are often used as synonyms for each other. Nevertheless, the enduring nature of values tend

I. Eilks & A. Hofstein (Eds.), Relevant Chemistry Education – From Theory to Practice, 101–118.

to set this term apart from other terms as Rokeach (1968) points out in differentiating between an attitude and a value in the following ways:

- An attitude is an organisation of several beliefs around a specific situation; a value is a single belief of a specific kind and is not object specific.
- An attitude is focussed on a specific object or situation; a value can be transcended to other objects or situations.
- An attitude is not a standard; a value is a standard and guides favourable and unfavourable evaluations of numerous attitude objects or situations.
- Attitudes are object or situation specific and great in number; values are general in nature and lesser in number.
- Attitudes determine behaviour, but are themselves determined by values; values occupy a more central position in one's personality makeup and cognitive system and therefore they determine attitudes as well as behaviour.

Similarly, in differentiating values and beliefs, Seah and Bishop (2002) contend that a belief is about the degree to which something is true, while a value is the degree to which something is important. Additionally beliefs exist in a context, while values exist in the absence of any context.

From this consideration of values, it is apparent that values is not a synonym for beliefs and attitudes as they are enduring principles or standards and not context specific.

VALUES AND LEARNING CHEMISTRY

Chemistry is a particular way of thinking (and acting) as it is a knowledge-seeking enterprise. In learning any discipline including chemistry, there are certain rules or paradigms that must be followed and it is within this paradigm that values underpin that discipline. Such values can be epistemic or sociological in nature. Epistemic values distinguish knowledge that is intrinsically worth knowing and include that knowledge that is currently accepted by the scientific community, particularly in terms of theoretical explanations (Allchin, 1998).

Sociological values consider both external and internal sociological perspectives. External sociological perspectives are concerned with values that will guide chemistry research, view chemists as experts that possess authority within their expert field and given their expertise, whether their research should be funded based on its benefits to society and the chemist's ability to communicate their research publicly. Internal sociological perspectives consider values associated with the practitioner themselves and will include the values the chemist holds as a member of a scientific community and also personal values as a member of society.

Values that underpin chemistry can include rational thinking, empiricism, parsimony (which can include reliability), robustness, fruitfulness, curiosity, skepticism, accuracy, reduction of bias (rather than objectivity), open-mindedness, creativity (which can include imagination, innovation, intuition, and guesses), interdependence (on other scientists and their research) and community practice (as in a community of scientists).

These values are not necessarily common to chemistry (or science) as they exist in other disciplines such as mathematics and history. What is unique to chemistry in particular, and science more generally, is the way such values play out in chemistry both individually and as a collective set of values. For example, rational thinking involves the development of an argument, reasoning, logical analysis and explanations. Rational thinking promoted universalist thinking as it involves the development of theories and hypothetical and abstract situations. In chemistry rational thinking is characterised by the ability to develop an argument through engaging in discussion and debate or seeking explanations for experimental data. In mathematics, logical thinking is characterised by understanding the role of proof and proving.

Interpretations of the same value in different disciplines can take very different forms, which can create tensions when learners try to make sense of these values across different disciplines. When learning chemistry, students will need to be aware of these values and their significance when learning chemistry and differences with values in other disciplines they are learning.

The inclusion of the Nature of Science (NOS) as a fundamental part of learning chemistry often means that the values that underpin chemistry are often explicit. This is not the case in many other disciplines such as mathematics. Despite this explicit articulation of values, teachers still need to interpret such values and promote their development in the classroom. These practices within chemistry classrooms are more often less obvious. For example, where do students have opportunities to develop an understanding of creativity and parsimony in their chemistry classroom? It may be possible to develop such an understanding by providing some definition around values that are essential components of learning chemistry. In this way teachers may interpret such definitions and provide their students with experiences that will encourage understanding of these values and how they underpin chemistry. Some definitions of values central to chemistry and therefor chemistry learning that are often not explicitly considered when learning chemistry are provided in Table 1.

The values in Table 1 present only some of the values that underpin chemistry as it focuses on only some of the epistemic and sociological dimensions of values of chemistry. However, providing definitions of fundamental values that underpin chemistry gives learners an opportunity to appreciate the attributes of chemistry as a powerful ways of knowing and acting. Other values such as reducing bias, interdependence and community of practice also need to be fostered when learning chemistry.

In the next section, we will explore how some expert chemistry teachers have attempted to create opportunities for students to develop an understanding of these values when learning chemistry.

Table 1. Some values of chemistry and their meaning

Value	Constructed meaning
Curiosity (includes intellectual curiosity and inquisitiveness)	Curiosity relates to not only the questioning but also to consideration of the wonder and mystery that is aroused when attempting to provide explanations for phenomena that occur in the natural world.
Parsimony	When there are competing explanations (hypotheses, models, systems etc.), the simplest explanation, model or system that accounts for most of the data is accepted for use. Note: The term "parsimony" derives from the Latin lex parsimoniae which broadly translates as the law of parsimony, law of economy or law of succinctness. In more recent times the phrase Ockam's razor has been used to describe this value of science. The razor is a principle that suggests we should tend towards the simplest explanation until such simplicity of explanation can be substituted for greater explanatory power. Its (the razor's) value lies in the justification of deciding between the competing explanations. Such justifications need to also take account of the plausibility, fruitfulness and robustness of such explanations.
Creativity	Creativity, particularly in thinking, is characterised by its apparent lack of connection to other ideas. Processes such as 'random thoughts', 'thinking outside the box', 'guesses', 'intuition' are often attributes of creativity. In attempts to promote the creative process it is important to not place parameters around thinking.
Open-mindedness	Open-mindedness means being receptive to the alternative and different ideas and opinions presented by others. It is also attributable to looking at data in alternative ways.
Rational thinking	Rational thinking, rationality or rationalism describe the cognitive process of reason, how one thought links to another. Rationality is different from logic in that it focuses on the notion of reason as a type of thought. Logic, on the other hand, is a process that attempts to describe the norms and rules by which reasoning operates, and in this way can attempt to teach orderly thinking. Logic is therefore one type of rational thinking. For example of rational thinking would include such things as skipping steps, working backwards, drawing diagrams etc., which are not part of logic.
Empiricism	Empiricism relates to knowledge that is derived from sensory experience (and includes direct and indirect observation). In this sense, it provides an alternative view to rationalism on the processes of knowledge creation, as rationalism is based on reason or thought. The power of these two seemingly opposing theories on knowledge creation is in recognising their differences and making judgements based on the differences.
Skepticism	Skepticism relates to a general attitude of doubt or questioning of knowledge, opinions, beliefs presented as facts, or claims that are made. Skepticism in science is often seen in the practice of subjecting beliefs and claims to scientific investigation (and further scientific investigation) in order to supporting their reliability.

(Corrigan, 2015)

TEACHERS' PROMOTION OF VALUES IN THE CHEMISTRY CLASSROOM

Our research has explored how teachers promote values within their science classes, particularly in secondary schools. Values are central to the teaching and learning process. As Hildebrand (2007) asserts no science curriculum is value-free and to develop lifelong scientific capability we need to "*design ways in which diverse value positions – of scientists, science educators, teachers and students – can be embedded in our curriculum*" (p. 45).

In studying science teachers in Victoria, Corrigan and Gunstone (2007) proposed a framework for exploring values under four broad themes, they were science as: a process, human qualities, cognitive dimensions, and societal dimensions. A number of different values of science, such as curiosity or empiricism, are considered including their meaning in a scientific sense and what might represent a manifestation of this value in the classroom. This broad framework provides a mechanism for giving insights into teachers' values by identifying particular pedagogical practices.

Hildebrand (2007) connected values and pedagogical practices when she stated that "*our pedagogy signals our values*" (p. 56). She proposed teachers' values as the central core that defines the personal principles and metaphors they live by, use to make decisions about what they believe, and how they behave. These personal principles define a teacher's philosophy of science education, help to frame their understandings of science education, and guide what they do in the classroom, as well as the pedagogical practices they adopt, adapt and develop. These pedagogical practices are what can be observed in the classroom (Figure 1).

The teacher sample for this research was generated from peer recognition of teachers as experts. The case studies presented here are representative of the sample of chemistry teachers from this research project.[1] The teachers reported here teach in both Australian government and private secondary schools, teach at both middle school (students aged 12-16) and at senior school (students aged 17-18). Teachers come from different states within Australia and consequently the assessment practices, particularly at senior school level are very different. For example, in Queensland students are assessed through assessment that their teacher has set and it is the assessment tools that are moderated by groups of teachers to be of an appropriate standard. In Victoria students are assessed through 66% related to a common externally set examination and 34% internal teacher assessment. In New South Wales students are assessed 100% based on their performance in an externally set examination. The teacher cases reported here come from Queensland and Victoria.

[1] Australian Research Council Research Project: Engaging science students' hearts and minds: Researching science teachers' professional learning in the development of contemporary understandings of scientific literacy.

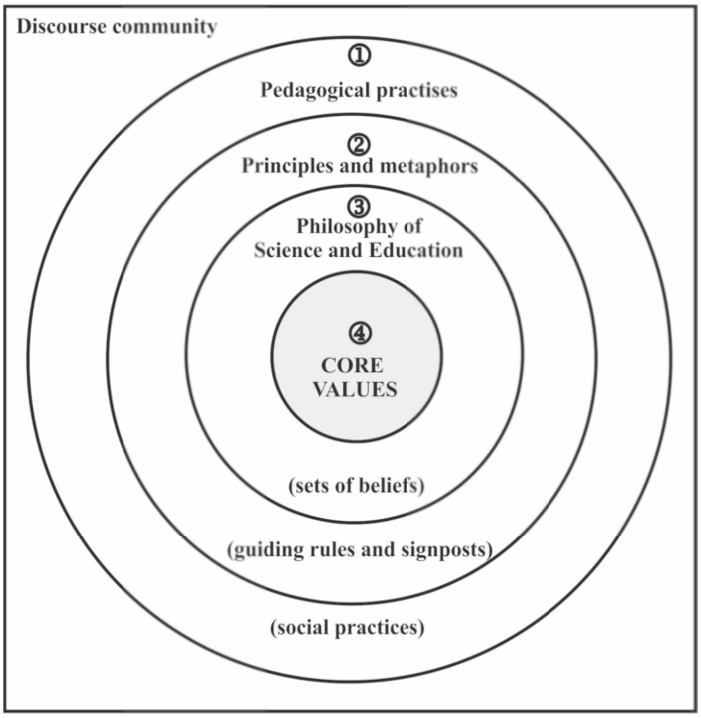

Figure 1. Pedagogical practices to values sphere (Hildebrand, 2007, p. 57)

Consideration of assessment practices at the senior levels is important as this constitutes quite high stakes achievement data for students, teachers and their schools, and may subsequently have an impact on their practices at these levels.

The research project involved these teachers in an initial interview to explore the conceptions of chemistry and the values that underpin chemistry and their chemistry teaching. Teachers were then video-taped teaching both a middle school and a senior school class. On completion of the interviews and video-tapes, each teacher discussed the data with the researchers to explore the values that they think are important and the values that were apparent in their classes. This data was captured in an agreed (by the teacher and the two researchers) case. In this way, there was collaborative exploration of how values underpinning their conceptions of chemistry manifested in their classrooms. Pseudonyms have been used to protect the identity of these teachers.

Shona

Shona is an experienced chemistry teacher of 25 years experience. She has taught both middle school science and senior chemistry in a number of Victorian government schools and has also been involved in teaching chemistry "methods" in teacher education programs.

Table 2 represents the occurrence of values that Shona identified as important in the initial interview and were apparent in the two lessons that were video-taped. We are equating importance with frequency in these interviews as teachers constantly referred back to these ideas indicating that they thought they were important. It is important to remember that the video data represents only two classes and so the inclusion of values will be dependent on the context of the lesson observed.

Table 2. Frequency of values present in Shona's interview and video

Values	Shona – interview	Shona – video middle school*	Shona – video senior school*
Curiosity	10	2	2
Longing to know and understand	4	1	1
Open-mindedness	7	3	0
Skepticism	9	0	0
Rational thinking	3	0	0
Reduction of bias	0	0	0
Empiricism	2	0	1
Integrity	0	0	0
Diversity in scientific thinking	0	1	0
Interdependence	3	1	0
Parsimony	3	0	1
Creativity	5	3	1
Science Community (co-operation, collaboration)	4	0	0
Accuracy	6	1	6
Reliability	0	0	2
Valuing process	3	0	2
Search for evidence (verifiability, demand for verification)	10	0	1

* The values in this table were collated based on the footage taken of two classes only, thus this data is dependent upon the content of the lesson and the teaching procedures being used that day and should only be taken as an indication of the values the teacher was displaying on that day.

From Shona's interview it appears that curiosity and search for evidence are the most important values. Shona values curiosity, search for evidence, and scepticism which are all more cognitive in their orientation (although curiosity can take on a human quality dimension if it is more about mystery and wonder) rather than values associated with human qualities, although open-mindedness is also important for her. In her middle school science class creativity and open-mindedness (more human qualities) are Shona's most common values present, with curiosity also evident. In her senior school class she emphasises the value accuracy, with curiosity, reliability and valuing process (all process values with the exception of curiosity) also evident. This may suggest Shona is more likely to promote values in her senior classes that are more related to adhering to science processes such as responding to questions and understanding content in acceptable ways.

From Shona's interview it is evident that she promotes curiosity and the search for evidence. Considering the teaching observed, Shona promotes creativity, open-mindedness and, especially in her senior class, accuracy. At the beginning of a year 11 (a senior class) chemistry class, Shona poses the question; Why is it important to think about experimental error and experimental design? A discussion then follows about scientists in industry. Shona also draws links to the student's assessment where she reminds them that they "*must record their observations carefully in their log book so that they can access the data later and use it to answer and apply knowledge. So, think about your observation and how you record them*." Shona sets her students to work on writing up a practical report for an experiment they have completed the previous lesson. She moves around having discussions with the students that quite often relate to the data they have collected and how they can use that data as evidence to support the claims they are making.

Shona often promotes thinking/communicating scientifically both in her interview and during her classes. During her interview Shona comments that "*The way that science is structured ... that it is about being curious and then having a question and working out how to problem solve and then sharing that by writing or talking to someone about what you've learnt*."

During one of her lessons, Shona spent time discussing the purpose of writing up a practical report with her students. She asked them if the order of the report was important and if so, why? She asked the students to consider the different ways that the data they had collected could be analysed and presented. Shona also discussed the different ways the students had approached completing the experiment, collecting data and constructing the report. In other words, Shona was talking with her students about communicating their ideas about doing science in ways that had meaning for them and a wider audience. She was asking them to consider the purpose for writing a report beyond just submitting it for assessment and helped her students to make links between their work and the way that scientists work.

Shona's agreed case is represented in Figure 2 below. The text represents the identification of values, that may or may not have been articulated in this case. Those not articulated are indicated with brackets.

SHONA'S CASE

It is evident that much of your teaching revolves around improving your students' ability to communicate their ideas. You clearly value all forms of communication whether it be writing, drawing, speaking, diagrams and you are always happy to have input from your students and go to great lengths to make sure that not only have you understood them but that their peers have as well.

You comment that "The way that science is structured [is] that it is about being curious and then having a question and working out how to problem solve (rational thinking) and then sharing that by writing or talking to someone about what you've learnt." This was evident in your teaching when you spent a great deal of time discussing the purpose of writing up a practical report and analysing the different ways that the experiment was completed (open-mindedness), in other words, getting students to communicate their ideas about doing science. From both your interview and your teaching, it is evident that you value curiosity in your students. "…getting the kids to question, be curious and wonder about things…" You are constantly providing them with opportunities to inquire about new things and make an effort to assist them to draw strong links between these inquiries, why they are completing them (longing to know and understand) and how it relates to the work of scientists.

"With the extended experimental investigation, they get these results that they put into a logbook, and they have to think about it before they do the next track, which is more in line with what real science is about."

"The linking. Looking at one experiment and seeing that you can take what you've learned here, and apply it to this next experiment. Then they have had to find ways to link the two together."

"So you're wanting kids to question or wonder why things are, then the topic of water is really good because it has got so many amazing properties. So you can start by saying have you ever wondered why water forms a droplet on this surface, but if I have it here it just sort of runs?"

This was evident in your teaching when you heightened the students' curiosity about the respiratory system by asking them how it linked to systems you had already studied (rational thinking). They responded well to this and were able to make many links which lead to the generation of an impressive group of words related to the respiratory system.

You are willing to accept the views of your students and work with them, even when they are not completely accurate. This is noticeable in the way you encourage students questioning, but work with your students to improve the way they formulate questions.

"When the students are generating their questions, you need to be involved in that, and talk to the students about what makes a good question because you can get some really ridiculous, far out questions. So you can talk to the students about shaping and rewording their questions."

You also consider problem solving (rational thinking) to be a big part of science, so it is not just about asking questions, but about solving them in a productive and thoughtful way. You say that it is really important to you that students are "…truly understanding how to ask questions but then know how to problem solve. Being presented with something and then work out how am I going to solve this? Particularly in subjects like chemistry, there's lots of problem solving and often mathematical [manipulations], and they often don't know where to start. They've got information in there, *but they can't interpret what is this question asking of me? How do I go about solving it, even though they've got the information up there [points to head]. And analysis and interpretation is very important, they're not very good at that. And the simple conclusion at the end, being able to say this is what I've learnt and this is how it links to this."*

You also try to encourage some skepticism in your students as you constantly question their ideas and ask for evidence to support their thinking. "Whereas, I think students look at their textbook and just see this series of facts and I don't even think they question where did this information come from?"

In the following quote you discuss a situation where you were discussing an exam question with your students and work with them to question the question.

"…let's look at this question, what topic is this from? OK this is an equilibrium question right, now, let's write down what are the main things we need to know about equilibrium. Then we write that down, OK, now let's look at this question, what is it trying to target here? So they can make more of link between this knowledge that they've got in their head and then see what part of equilibrium is it wanting you to demonstrate?"

As you have said, this helps your students make links, but it also helps them understand how a question is constructed, how you might go about solving it and encourages them to question the validity of the actual question before they even attempt it (skepticism). You also appreciate accurate, authentic data collection and look for simple, but clear explanation (parsimony) rather than a longer highly sophisticated one.

Figure 2. Shona's agreed case

Greg

Greg has taught for approximately ten years as he had a career prior to teaching in an environmental research laboratory. He has taught middle school chemistry and some senior chemistry, but predominantly teaches biology at the senior level. Greg teaches in a large private boys school in Queensland.

Table 3 represents the occurrence of values that Greg identified as important in the initial interview and were apparent in the two lessons that were video-taped. Again, the video data represents only two classes and so the inclusion of values will be dependent on the context of the lesson observed.

From Greg's interview, longing to know, empiricism, creativity and accuracy are the most important values. These values fall across a number of value categories (as identified by Corrigan and Gunstone, 2007) such as cognitive (longing to know), science process (empiricism and accuracy), and human qualities (creativity).

From the middle school data, Greg's lesson exhibited many examples of accuracy (science process), integrity and creativity (human qualities). Again the context of the lesson is important here, as students were required to undertake a practical activity that they had to design themselves in teams.

From the senior school classes' data, there is a spread of values manifested across the classes, with some more diverse than others. For example, Greg's class indicates a limited manifestation of values, as it centred around two main activities; making a model and role-playing their understanding. The manifested values include creativity (human qualities) and science community (science process). Greg's agreed case is represented in Figure 3.

Table 3. Frequency of values present in Greg's interview and video

Values	Greg – interview	Greg – video middle school*	*Greg – video senior school*
Curiosity	1	1	0
Longing to know and understand	3	0	0
Open-mindedness	2	0	0
Skepticism	0	0	0
Rational thinking	0	0	0
Reduction of bias	0	0	0
Empiricism	3	1	0
Integrity	0	6	0
Diversity in scientific thinking	1	0	0
Interdependence	2	2	0
Parsimony	0	0	0
Creativity	3	5	2
Science Community (Co-operation, collaboration)	0	0	2
Accuracy	3	8	0
Reliability	0	2	0
Valuing process	2	6	0
Search for evidence (Verifiability, demand for verification)	0	0	0

* The values in this table were collated based on the footage taken of two classes only, thus this data is dependent upon the content of the lesson and the teaching procedures being used that day and should only be taken as an indication of the values the teacher was displaying on that day.

GREG'S CASE

It is evident that much of your teaching revolves around improving your students' ability to gather data accurately. You clearly have experience with accuracy in industry and this is evident from your comment that, "what they don't realise is that in industry accuracy = dollars." You take the opportunity to emphasise this with your students during classes when you remind them to calibrate the scoop scale every time they use it and to keep it level on the bench when they are taking readings. You also comment in your interview that, "when teaching the scientific method I like students to take their time, calibrate and collect data with accuracy and safety in mind."

You comment that, "students should always measure and record accurately." Linked with this is an emphasis on working with integrity. You encourage your students to take their time, avoid mistakes and collect accurate worthwhile data. You would rather them report what they actually did and saw rather than make it right just to get the expected result.

You appreciate your students following guidelines and like them to write the guidelines themselves. You comment in your interview that "during the extended experimental investigation (EEI), they keep a journal of research but most marks are for process, content and originality." The processes in science are important in your teaching and this is evident when you ask your year 9 students where they will start today? Or what they think comes next in the process? You encourage the students to work through things and make links between what they have done and what they are going to do (rational thinking).

You like your students to be creative in science and this is evident when you encourage a small group of year 9 students to investigate using a blender to crush up the ore for their mining experiment. You also ask your year 12 students to use plasticine models and a role play to reinforce the learning that has taken place in the classroom and to describe their understanding of synapse. You would like there to be more chances for your students to make decisions, and be creative, with their assessment, "with year 12's the ideal assessment would be the extended experimental investigation (EEI) but with a broader spectrum of topics and weekly logbook checks." This quote also indicates the value you place on empiricism and you explore this further when you comment that "at years 8, 9 and 10 they do an extended experimental investigation (EEI) that is scaffolded at different levels. The year 9's do one on mining and the year 10's do a rat and toad dissection to compare the anatomy." You believe that students learn from direct observation and that they should collect data as they progress through an experiment using their logbook to record what they see, smell, hear, feel and taste. You emphasise this in your teaching when you have a discussion with your year 9 students about the difference between qualitative and quantitative data and why they need to collect both. You also talk about the different ways that these types of data can be recorded and displayed.

Figure 3. Greg's agreed case

Kate

Kate has been teaching chemistry and science for 15 years. She is currently the science coordinator in a large Queensland private boys school and provides many science professional development opportunities for her science staff. She is also heavily involved in moderation of assessment at Year 12 (final year of schooling) both with her staff and staff in other schools.

Table 4 represents the occurrence of values that Kate identified as important in the initial interview and were apparent in the two lessons that were video-taped. Again, the video data represents only two classes and so the inclusion of values will be dependent on the context of the lesson observed.

Table 4. Frequency of values present in Kate's interview and video

Values	Kate – interview	Kate – video middle school*	Kate – video senior school*
Curiosity	0	0	1
Longing to know and understand	1	0	1
Open-mindedness	1	0	0
Skepticism	1	0	0
Rational thinking	0	0	1
Reduction of bias	0	0	1
Empiricism	1	0	3
Integrity	0	0	0
Diversity in scientific thinking	1	0	0
Interdependence	3	3	1
Parsimony	0	0	0
Creativity	2	0	0
Science Community (Co-operation, collaboration)	0	0	0
Accuracy	0	0	3
Reliability	0	0	1
Valuing process	4	0	1
Search for evidence (Verifiability, demand for verification)	2	0	1

* The values in this table were collated based on the footage taken of two classes only, thus this data is dependent upon the content of the lesson and the teaching procedures being used that day and should only be taken as an indication of the values the teacher was displaying on that day.

Kate's interview indicates that the most important values for her appear to be valuing process and interdependence (valuing other scientists and their research – this value often provides links to how science interacts with nature and human beings and the impact of science on our lives).

Kate's middle school lesson, involved the students using a computer simulation that saw the students behind the wheel of a car in situations where they would need to brake suddenly. Most of the lesson involved all students in "having a go" so the opportunity for a wide range of values to be exhibited was limited, however interdependence was represented and Kate highlighted this value as important in her interview.

In contrast to her middle school class, Kate's senior school class shows a diversity of values manifested, the most frequent being empiricism and accuracy. Given this lesson was a chemistry class where the students were completing several experiments to test for solubility as they recorded their observations and then looked for patterns, this is not surprising. Kate's agreed case in represented in Figure 4.

KATE'S CASE

You value the processes of science and comment that "we do these investigations at all grades and provide year 8 with highly structured log books, and year 9 and 10 get a more generic style log book, it still has questions, but they are more general as year 9 and 10 are able to choose a topic from a carefully produced list of 3-5." You offer students guidelines to follow but eventually, you ask the students to create the guidelines themselves, an indication that you also value creativity in your students.

During the year 12 chemistry class that was filmed you asked the students to follow a process to complete some experiments, but you also asked them to follow a process to collect data. You asked some of your students' questions like "is it dissolving? How can you tell? Is it changing colour? Have you got that written down?" This required your students to observe carefully what was happening in the test tubes and to record their direct observations in the table as you suggested (empiricism). You wanted the students to be confident about what they were seeing and to draw conclusions from the investigation that they carried out (rational thinking).

Having the students collect accurate data was also something that you promoted during the year 12 chemistry lesson. A few of the students were confusing a meniscus for the substances not dissolving. In an effort to increase the accuracy of what they were doing and observing you worked with the students as they repeated the experiment and made suggestions about what they could do to improve the process and improve the result (reduction of bias). For example; increasing the volume of the substances and waiting longer before recording their observations.

During your interview you mentioned an assessment piece that you really enjoy, "…the boys make a decision about the best type of fuel for cars – this is their basic brief. They need to define what would make it best – e.g.: environmentally sound, high energy, low cost, access, processing (interdependence). They then need to decide how to get the answer to the problem (rational thinking), set the parameters of the tests, do the testing, analyse the results and examine the reliability of the results in terms of secondary data and the investigation process that they undertook." This is an indication that you value creativity as you encourage your students to design their own experiments and be innovative in the way they interpret and present their results.

Linked with this is your promotion of the search for evidence, as you encourage students to be "…able to reflect on an investigation and acknowledge the validity or lack of validity of a statement based on findings." You want your students to support their ideas with evidence and to reflect on how they came to their conclusions given the data they collected during their investigation.

You believe that students should be able to apply their science knowledge to make decisions about issues related to the world this is evident when you suggest that there should be opportunities, "...that require students to apply their knowledge and respond to an issue of science relevant to the general public for example global warming." (interdependence).You encourage your students to take an interest in the interconnectedness of science and the quality of human life and believe that it is important for students to do "…things like being able to discuss whether a rise in CO2 has caused the temperature to rise or vice versa." This is evident in your teaching when you discuss with your year 10 class the factors that affect the time it takes for a car to stop. Your students raise issues such as the condition of the tyres and brakes on the car as well as the road and weather conditions. The discussion eventually moves to talking about taking drugs and consuming alcohol as well as being too tired to drive a car. The discussion clearly links human beings and technology with what you are talking about, and in this case calculating, during the science lesson.

Figure 4. Kate's agreed case

CONCLUSION

From our research it is apparent that teachers do indeed have values that underpin how they think about chemistry and consequently how they teach chemistry. There is recognition that chemistry (and science) is not value free. From the cases represented above, the values range across all the categories of science as process, human qualities, cognitive dimensions, and societal dimensions as identified by Corrigan and Gunstone (2007), which broadly match the theoretical perspectives of epistemic and sociological values associated with science (and chemistry).

How these different values manifest in the teachers' practices is heavily dependent on the teaching context. This is particularly evident when teachers are teaching at year 12 level (the final year of schooling) where the assessment practices become more high stakes for the students and their teachers. From the interview data, there was clear evidence indicating that teachers want to maximise the opportunities for their students, particularly at this level, and they are more forensic in the interrogation of the curriculum and the way students will be assessed.

In Victoria, with an external examination accounting for 66% of the students' final mark, there is close attention to the content and processes of science that will form the basis of this assessment. Shona indicates this with her focus on the experimental process and the unpacking of examinations questions so that they can communicate their understanding effectively. While Kate emphasises similar values in her year 12 class around the processes of science, there is less emphasis on the articulation of ideas as her students are assessed internally. In Queensland teachers set the assessment tasks for their students based on what they have learnt and it is the assessment tasks that are moderated (and not the students). Greg experiences the same assessment practices in Queensland as Kate and subsequently takes a more creative approach to assessment in year 12. This also means that Kate and Greg can have more control over what is done in the classroom as they also control the assessment of this learning to a large extent.

The degree to which values are made explicit to teachers in the intended curriculum and subsequently explicit to students in the implemented curriculum and how students articulate these values after experiencing the curriculum will provide opportunities for further exploration. What our research has highlighted is that while some values are explicit, particularly if the curriculum has a strong focus on the NOS, other values related to sociological or human qualities and societal dimensions often remain implicit. If such values are only implied in the curriculum, then the responsibility for the inclusion of such values rests with those values teachers hold. Such values will vary based on the teachers' experiences. For example, Greg, with his experience of working in a science laboratory, holds much stronger values in the area of accuracy and integrity than either Shona or Kate. His concept of accuracy is also more than just about data, which appears to be more of Shona and Kate's focus, and involves more about the way scientific processes are carried out with questions such as what processes need to be accurate and what do not.

In Australia, teachers are significantly responsible for the development of the implemented curriculum as there is recognition that teachers needs to contextualise learning for their students. The intended curriculum outlines what is to be learnt as well as when and to some extent why; it does not define how it is to be learnt. There are not specific learning units and assessment tasks are relatively undefined in nature in the intended curriculum.

From this research it is clear that teachers do have values that underpin their concepts of chemistry (and science) as well as their teaching of chemistry (and science). What is not so clear is how teachers make these values clear to their students. The teacher participants in this research all reported that focussing on the values of science as well as the values that they hold in this respect as chemistry/science teachers and provided significant focus for them in reminding them about what was important in their teaching and how they represent this to their students. They also reported that they felt focusing on values and making such values explicit for their students would provide a more "authentic" representation of chemistry and science for their students. The teachers recognised that they left too much "unsaid" for their students so that the students had to make up their own meanings rather than building a shared meaning for these values. This response from the teachers has led to the exploration of further research that focusses on teachers taking particular values as the focus for the learning they do in their classroom. For example, Shona reported that she has taken a more focused approach to how she fostered creativity in both her middle and senior school classes as a response to her experiences in this project. Herein lies some real benefit of this research with teachers as it has provided them with a reflective frame for analysing their own chemistry and science teaching that they can share with their science colleagues in school. There are also opportunities for such professional learning opportunities to extend across disciplines so that teachers can be more explicit about how different values manifest in different disciplines. The notion of evidence is a prime example, where in science evidence is expected to be based on empirical data that has value, whereas in history, evidence is based on interpretations of past events and can never be empirical in nature.

A focus on values has also forced these teachers to think about what values do they represent in the chemistry classrooms and which ones do they not. The agreed cases played a pivotal role in highlighting for these teachers which values they preferenced and which ones they ignored. The classification of values as falling under broad themes of science as process, human qualities, cognitive dimensions and social dimensions was an extremely useful one for the teachers as they could understand these themes far better than theoretical frames such as epistemic and sociological values. Indeed, these categories used by Corrigan and Gunstone were generated from professional learning sessions with science teachers and present these ideas in ways that are more accessible for teachers. The teacher participants all reported that as they developed their lessons for students across the years they would be able to use these categories to ensure that provided specific learning experiences for their students across these categories.

In conclusion, a focus on values in chemistry and chemistry education has provided many benefits for the teachers. Not only have they re-examined their own values in terms of chemistry and their teaching of chemistry and the potential this provided for further professional learning in this area, they have also been alerted to the potential such a focus has in their interpretation of the intended curriculum and how students can articulate the values they are developing in relation to chemistry and science and how these values are nuanced in science as opposed to other disciplines. Making such nuances explicit helps students distinguish the uniqueness about each of the disciplines they engage with in their school and may have benefits in assisting their participation in interdisciplinary activities.

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YEHUDIT JUDY DORI AND SHIRLY AVARGIL

7. PROMOTING METACOGNITIVE SKILLS IN THE CONTEXT OF CHEMISTRY EDUCATION

Scientific literacy, thinking skills and metacognition continue to be increasingly important goals of science education reforms. These goals can be achieved via learning science in context and learning scientific concepts and processes through real-world problems. The theoretical framework of this chapter builds on theories of Flavell and Bandura. Following the distinction Flavell made between cognition and metacognition, and based on Bandura, we have adopted the assertion that self-regulated learning (SRL) is composed of cognition, metacognition, and motivation. In this chapter, we use the construct students' actual knowledge as the knowledge at the cognitive domain, and students' perceived knowledge as the knowledge at the metacognitive domain. While our study does not focus on motivation, learning in the context of food chemistry, environment and societal problems, served as a vehicle for motivating the students to study chemistry. We present students' assignments as examples that focus on several topics: food, energy, and reaction rate. These assignments will serve as a basis for illustrating materials from the classroom. The Taste of Chemistry module will also serve as the research setting. Students' self-regulated learning and the effective use of chemistry understanding levels are promoted via a built-in metacognitive tool. Our results indicate the potential contribution of self-regulated learning and metacognition to chemistry education.

INTRODUCTION

The first decade of the 21st Century was characterized by reforms in science education in general and chemistry in particular. Scientific literacy and thinking skills continue to be increasingly important goals of science education reforms. These goals can be achieved via learning science in context (Gilbert, 2006), learning scientific concepts and processes through real-world problems, case-studies, or adapted scientific articles (Avargil, Herscovitz, & Dori, 2012; Yarden, 2009). Metacognition can also serve as an important vehicle in promoting science education.

The theoretical framework of this study, which builds on theories of Flavell (1979, 1981) and Bandura (1986, 1997), is described in detail in the next section. Our research was conducted as part of the chemistry curriculum reform in Israel. The chapter *Goals for science education* of the NRC report (2007) emphasized the

I. Eilks & A. Hofstein (Eds.), Relevant Chemistry Education – From Theory to Practice, 119–141.

importance of developing aspects of metacognition in science education for improving students' understanding of scientific processes and monitoring their academic success. These ideas were applied while designing the framework for developing a new chemistry curriculum for Israeli high school students who elected to major in chemistry. One of the new learning modules in the reformed chemistry curriculum is titled *Taste of Chemistry* (Herscovitz, Kaberman, & Dori, 2007). This module, which was written for 11th grade chemistry majors in both Hebrew and Arabic, may serve as an example of integration of metacognition components into the curriculum and their implementation. *Taste of Chemistry* integrates context-based learning, chemical concepts, and a specially-designed metacognitive tool, designed as a scaffold for meaningful and self-regulated learning (SRL). Students' self-regulated learning and the effective use of chemistry understanding levels were promoted via its built-in metacognitive tool. This approach is described by Veenman (2012) as a top-down process, in which students gain the ability to monitor the task on hand by self-instructed metacognitive prompts.

The context of food chemistry was chosen as the focus of the newly designed module since food is an interesting topic that is highly relevant to youngsters. Accordingly, the module aims to promote students' motivation through learning in context by linking the subject matter to daily life food-related issues. Food and nutrition is an interdisciplinary subject, which, in addition to chemistry, involves a variety of disciplines, including health, biology, physiology, physics, and psychology. Non-the-less, food and nutrition had not been included in the traditional chemical education in Israel before the reform started. Researchers claimed that learning science in context has the potential to motivate students while engaging them in the learning process and triggering their curiosity (Watanabe, Nunes, Mebane, Scalise, & Claesgens, 2007).

Following the distinction Flavell (1979, 1981) made between cognition and metacognition, and based on several studies (Boekaerts, 1999; Herscovitz, Kaberman, Saar, & Dori, 2012; Schraw, Crippen, & Hartley, 2006; Schraw & Moshman, 1995; Zimmerman, 1986, 2001), we have adopted the assertion that SRL is composed of cognition, metacognition, and motivation. In this paper, students' actual knowledge is knowledge at the cognitive domain, and students' perceived knowledge is knowledge at the metacognitive domain. These constructs will be further explained and justified in the theoretical background section. While this research does not focus on motivation, learning in the context of food chemistry, which was part of the research setting, served as a vehicle for motivating the students to study chemistry.

In our study, students' monitoring of their actual knowledge, measured by their choice to respond to a specific task from a pool of tasks in the questionnaire, is evidence of their knowledge of regulation, which, in turn, is part of metacognition. Kipnis and Hofstein (2008) argued that when a student chooses an inquiry question from a set of questions, the selection is made following a metacognitive process in the student's mind. Other researchers noted that self-efficacy and perceived efficacy for self-regulated learning can enhance academic performance (Caprara et al., 2008; Bouffard-Bouchard, 1990). As suggested by Caprara and colleagues (2008), there is difference between gaining the knowledge of how to regulate one's learning, and being able to use this knowledge in different context-based tasks. The *Taste of Chemistry* module, developed as part of our research, aims at both developing and applying students' metacognitive knowledge. The research objectives were to investigate the effect of the combination of learning in context and the use of a specially-designed metacognitive tool on 11th grade chemistry students' (a) perceived and actual knowledge of food chemistry and (b) variety of chemistry understanding levels used in their responses.

The module included guided assignments into which the use of the metacognitive tool was embedded. The tool enabled students to regulate the quality of their responses to given assignments based on the four recognized chemistry understanding levels: macroscopic, microscopic, symbolic, and process (Dori & Hameiri, 2003; Gabel, 1998; Johnstone, 1991; Robinson, 2003). The tool served also as a scaffold for constructing knowledge expressed through meaningful answers to the given assignments. The different attributes of the module (i.e. integration of metacognition elements, context-based learning, chemical concepts, and a specially-designed metacognitive tool for meaningful and self-regulated learning) reflect the variety of relevance dimensions in chemistry education (Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013). In the individual dimension the module contributes to improving students' self-regulation, in the societal aspect students are encouraged to be involved in a variety of disciplines including health, physiology, and psychology, and in the vocational dimension module exposes the students to application of chemistry in food chemistry, nutrition, and medicine. These aspects are important for their daily life as well as to their future and personal growth as educated citizens.

We first present the theoretical background of self-regulated learning and metacognition in science education. We then describe the research objectives, research setting and design, including the *Taste of Chemistry* module, research participants, tools, and methodology are presented next. The research findings and discussion sections focus on students' perceived and actual knowledge as well as the variety of chemistry understanding levels students used in their responses. We conclude the discussion with an epilogue on implementation of the Israeli reformed curriculum, which was gradually extended to the national level in the years that followed our study. We shortly describe the intervention effect on students' actual knowledge, based on their achievements in the national matriculation examination. Finally, we summarize the research contributions and recommend further research.

THEORETICAL BACKGROUND

Flavell (1979, 1981) defined metacognition as *knowledge and cognition about cognitive phenomena*. Flavell, Miller, and Miller (2002), who surveyed the large body of literature on metacognition since the 1970s, similarly defined metacognition as cognition about cognition. According to Flavell (1979), metacognitive knowledge is classified into person, tasks and strategies (Figure 1).

More specifically, he described metacognition as knowledge about peoples' cognition, cognitive tasks, strategies that can be applied to solutions of different tasks, and skills for monitoring and regulating cognitive activities.

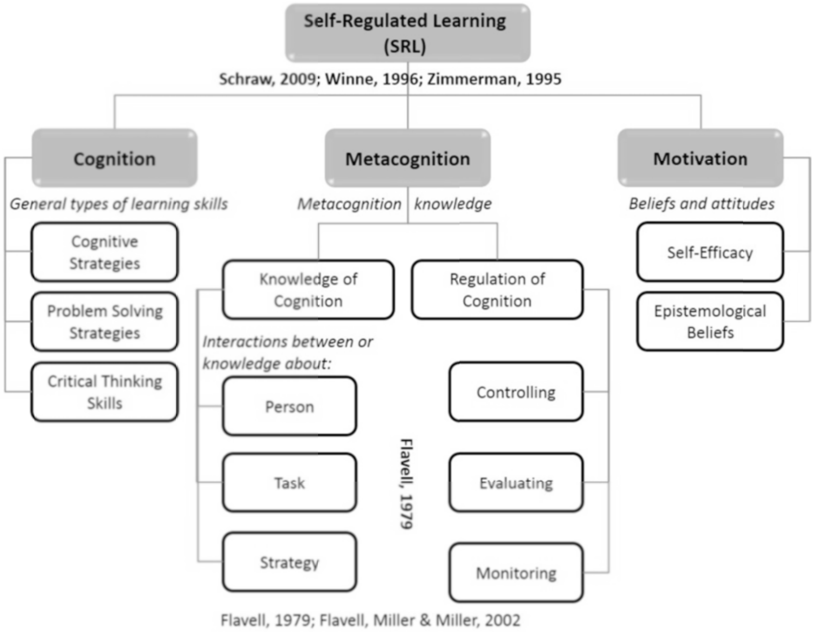


Figure 1. The hierarchical relationships among the components of self-regulated learning – the theoretical basis of our study (based in part on Herscovitz et al., 2012)

Self-Regulated Learning (SRL)

As part of his social-cognitive theory, Bandura (1986) claimed that SRL has three elements: personal, behavioral, and environmental. He applied SRL to several settings, such as school and classroom learning. Bandura (1997) also defined self-efficacy as one's perceived ability to apply actions for gaining a predetermined performance in a given task. Self-efficacy relates to choice of tasks, perseverance, effort, and strategies (Bandura, 1997). Students need to first set goals, and then select strategies that help achieve these goals, implement the strategies, and monitor advancement towards the goals (Schunk & Zimmerman, 1994). As presented at the top of Figure 1, SRL consists of three main components: cognition, metacognition, and motivation (Schraw, 2009; Winne, 1996; Zimmerman, 1995, 2000). Focusing on writing in academic settings, Pajaresa (2003) studied the relationship between self-efficacy, other motivation constructs, and writing outcomes. He found that students' confidence in their capabilities influence their writing motivation and outcomes. Teaching metacognitive knowledge and skills calls for integrating special instruction modes into students' learning (Schraw, &

Moshman, 1995; Zohar, 2012), a call that guided the development and integration of a metacognitive tool in the *Taste of Chemistry* module.

Learning requires self-regulation processes, including planning, monitoring, regulation, and reflection (Azevedo, 2009). Self-regulatory skills improve students' ability to control their learning and learning outcomes (Caprara et al., 2008; Zimmerman, 2000). Consequently, SRL positively impacts academic performance and motivation (Dignath, Buettner, & Langfeldt, 2008). Winne (1996) noted that students who are explicitly taught about knowledge and the use of skills usually become self-regulated learners. Indeed, teachers can promote SRL and meta-strategic knowledge by emphasizing learning strategies or by creating appropriate learning environments that encourage students to organize information and plan their learning (Kramarski, & Mevarech, 2003; Kistner et al., 2010; Zohar, 2012).

Most SRL models propose common sequences for students to pursue while performing tasks. The student should assess the usefulness of his/her strategies for understanding the learned topic, make adjustments in his/her behavior, and decide when, how and what to regulate. The regulated learning can have a positive effect on performance and achievement (Winne, 2001; 2005; Vrugt & Oort, 2008; Zimmerman, 2008).

Veenman (2012) suggested that recurrent problems with metacognition research arise not only from proliferation of terminologies, but also from disagreement among researchers about the components of metacognition and the relationships among them. Researchers noted that the nature of metacognition is not well-defined and fuzzy (Brown, 1987; Georghiades, 2004; Veenman, Hout-Wolters, & Afflerbach, 2006). They stated that due to the complex relationships between cognition and metacognition, it is difficult to differentiate between these two closely related constructs. Cognition is the knowledge essential to perform a task and includes a variety of learning skills students apply to complete this task, as shown in Figure 1 (Schraw, 2001). Metacognition is the knowledge about and regulation of the cognitive activities students carry out during learning processes (Brown, 1987; Flavell, 1979). Metacognition was later augmented to also include metacognitive knowledge, beliefs, awareness, and self-regulation.

Researchers have distinguished between knowledge of cognition and regulation of cognition, claiming that metacognition is composed of both. Monitoring, a component of regulation of cognition, is the relation between the perception of performance and the actual achievement (Metcalfe, 1998). Perception of performance may affect the length of study time as well as the level of actual performance (Pressley & Ghatala, 1988). The selection of an item to respond to is part of a regulation process. We argue that a metacognitive process takes place in the students' mind while monitoring their actual knowledge when they choose to respond to a specific question from a pool of questions. This process is an evidence of their knowledge of regulation, which, in turn, is part of metacognition.

Assessing metacognition

Metacognitive knowledge was initially related to assessing a person's prediction about performance. However, tools for assessing metacognition are limited since they are often designed to satisfy the needs of a specific research and may therefore not be suitable for identifying metacognitive knowledge skills (Veenman, 2012). Inconsistencies in the definition of metacognition raised difficulties in assessing metacognitive knowledge and skills (Georghiades, 2004). Schraw (2009) suggested that researchers should define categories for assessment in a way that is conducive to well-expressed models of metacognitive monitoring.

Bannert and Mengelkamp (2008) pointed to the need to design and validate metacognitive assessment methods. The level of metacognition students gain as a result of a specific treatment can be assessed by a variety of research tools, including questionnaires, interviews, think aloud protocols, asking students to respond to tasks, and observing students and/or their teachers (Azevedo, 2009; Bannert & Mengelkamp, 2008; Georghiades, 2004; Thomas, 2003). For example, Dunlosky, Serra, Matvey, and Rawson (2005) asked participants to make metacognitive judgments that expressed their confidence in the accuracy of the judgments of their learning. Ackerman and Goldsmith (2011) claimed that given sufficient time for performing a given task, students' perception of their performance (subjective, metacognitive domain) is related to their ability to monitor the learning process and eventually affects their actual knowledge (objective, cognitive domain). Thus, a high perception of performance reflects positively on the actual performance. Thiede, Anderson, and Therriault (2003) have found that when students' metacognition was improved, it was possible to improve their learning outcomes. Cognitive psychologists claim that metacognitive theories of learning address the interplay between objective (cognition) and subjective (metacognition) aspects of the learning process (Ackerman & Goldsmith, 2011). In our research, questionnaires were used in order to assess students' cognitive and metacognitive knowledge while learning the *Taste of Chemistry* module.

RESEARCH OBJECTIVES

The research objectives were to investigate the effect of the combination of learning in context and the use of a specially-designed metacognitive tool on 11th grade chemistry students' (a) perceived and actual knowledge of food chemistry; and (b) variety of chemistry understanding levels used in their responses.

Research setting and design

Science education curricula in Israel are determined by the relevant science subject matter committee. In chemical education, this committee includes chemists, chemical educators, the National Chemistry Superintendent, district-level mentors, and senior chemistry teachers. Together, they discuss and agree on both the content and pedagogy since at the end of 11th and 12th grades all the chemistry majors and honors are required to pass the same standard matriculation examinations. As part of a fundamental reform in the chemistry curriculum in Israel in the last decade, several learning modules were developed, including *Taste of Chemistry*. Until recently, teachers could choose whether to teach the new curriculum in their classes or continue with the traditional curriculum. The reformed curriculum has changed the way chemistry is taught and studied in Israel, making it more interesting and relevant to the students' lives (Barnea, Dori, & Hofstein, 2010).

The *Taste of Chemistry* module, designed for 11th graders who choose to take advanced chemistry studies, incorporates the four chemistry understanding levels as a major basis for its built-in metacognitive tool. The learning module, which played a key role in the major fundamental chemistry curriculum reform, integrates chemical concepts and processes of food chemistry, which focus on nutritional, health, and social aspects, with higher order thinking skills.

Researchers have found that it is important to consider both motivation and self-regulated learning in order to improve students' performance (Pintrich & De Groot, 1990). They argued that students who believed that what they had learned was interesting and were motivated to learn were more engaged in the learning process and more likely to self-regulate their learning.

The three main topics of the module – lipids, carbohydrates, and proteins – are taught in a context-based approach with real life problems that draw upon several disciplines. For example, in the proteins topic, in order to understand the importance of amino acids in our diet, the chemical structure of vital amino acids is studied along with their prevalence in several foods, such as soy beans.

Real world nutrition topics present opportunities for both teachers and students to study chemistry in the context of food while employing the notion of chemistry understanding levels to explain related facts and phenomena. Selected topics, concepts and processes in the *Taste of Chemistry* module, which demonstrate these principles, are described Avargil et al. (2012).

Chemistry understanding levels and their application in the metacognitive tool

The four chemistry understanding levels, the macroscopic, microscopic, symbolic, and process levels (Dori & Hameiri, 2003; Gabel, 1998; Johnstone, 1991; Robinson, 2003) are crucial for deep, meaningful understanding of chemistry. Recent research shows that using these four levels can improve students' higher order thinking skills, such as posing questions, modeling, graphing, and transfer (Dori & Kaberman, 2012; Dori & Sasson, 2008; Herscovitz, Kaberman, Saar, & Dori, 2012).

The macroscopic level refers to the description of a phenomenon as perceived by our senses, such as vision and hearing. The microscopic (molecular) level refers to the particles – molecules and atoms – and their chemical interactions. The symbol level refers to the description of substances and processes by means of chemical formulae, chemical models, chemical equations, and graphs (Dori & Sasson, 2008; Johnstone, 1991; Gabel, 1993; Wu, Krajcik, & Soloway, 2001).

Finally, the process level refers to the dynamic nature of chemistry via the description of how substances react with each other (Dori & Hameiri, 2003; Dori, & Sasson, 2013; Robinson, 2003).

A specially-designed metacognitive tool, which builds on these four levels, was provided to both experimental teachers and students and was instrumental in our research. While studying the *Taste of Chemistry* module, students were exposed to strategies for solving problems in food chemistry through the use of the four chemistry understanding levels as a key element of our metacognitive tool. The tool was not a mere reminder of the chemistry levels; it included metacognitive elements for monitoring and assessing students' responses based on criteria that examined which and how many chemical understanding levels were used to construct a response for each assignment. These criteria were made known to the students, thereby serving as scaffolds for building meaningful responses and monitoring their learning processes.

The following assignment (Figure 2) is part of another new learning module titles Energy in the Rhythm of Chemistry (Carmi, Wisselberg, & Dori, 2007). It is aimed at developing your *thinking about thinking*. In your responses try to use different levels of chemical understanding and think what levels are required for giving a complex response to the given assignment.

Bring a burning match close to a candle thread and then to a wooden tooth pick. In both cases the reaction is exothermic. In which case is the activation energy higher?
While using a stove or a lab burner, a chemical reaction of burning the cooking gas occurs.
Is the reaction endothermic or exothermic? Explain your reasoning.
In order for the gas to burn, you need to use a match or some other means in order to start the burning process. Please explain why.
Draw a schematic graph that qualitatively describes the process of burning the cooking gas.
N_2 absorption from the soil is a multi-stage process in which the end product is $NH_4^+{}_{(aq)}$.This is a first-order reaction. It proceeds at a rate that depends linearly only on one reactant concentration – nitrogen in our case. The reaction rate is K[N_2]. K is the temperature and it depends on different type of soils – A, B, or C (see the table below).

Soil Type	Nitrogen concentration in the soil (Kg per area unit per year)	K – reaction rate
A	1000	0.01
B	2000	0.03
C	2000	0.06

Calculate the rate of nitrogen absorption per area unit per year in each of the soil types. Explain your calculations.
Why in soil type C, which exists in a tropical climate (which is hot and humid), the absorption rate is higher than in other soil types? Explain your reasoning using as many chemistry understanding levels as possible.

Figure 2. An example of applying the chemistry understanding levels in one of the class assignments while teaching the Energy and Reaction rate module

The example presented in Figure 2 is an assignment from the module energy and chemical rate, which is an advance topic. The topic is taught in 12th grade after students studied the module Taste of Chemistry. Both modules included metacognitive prompts and instruction to foster meaningful learning. Each chapter of the *Taste of Chemistry* module contains several assignments, requiring the students to meaningfully integrate as many chemistry understanding levels as possible in their guided assignments. Figure 3 is an example of such assignments.

Sorting Amino Acids

Time out:
"Thinking about thinking" while using chemistry understanding levels

Chemists are used to relate to chemical information at several understandings levels. This assignment includes questions in which you are required to answer using different chemistry understanding levels.
The first question of this assignment concerns the symbol level. Here, you are required to identify the side chain of the different amino acids.
In the second question, which relates to the symbol, microscopic and process levels, you need to explain the ionization process of the amino acids.
Make sure to use these understanding levels in your answer.

I. Based on the table of the 20 amino acids and their side-chains, draw the structural formula of Threonine, Tyrosine, and Isoleucine in pH=7.
II. Draw the structural formula of Aspartic acid in acidic, basic, and neutral solutions and explain the differences between the three structures.

Figure 3. Applying the metacognitive tool in one of the assignments in the module

In the guided assignment described in Figure 3, which is representative of the assignments at the beginning of the module, the students are exposed to a metacognitive strategy when answering open-ended questions in chemistry. Throughout the module, while constructing their answers, students are encouraged to think about how the different levels of chemical understanding complement each other and to incorporate the various aspects exposed by each level in their argumentations.

Indeed, students made extensive use of the chemistry understandings levels as a scaffold for building complex answers, as is evident from the following comment made by student G. during an informal class discussion: "*When I write an answer and think about the different chemistry understanding levels, I feel that my answer is fluent... It helps me in checking my answer after I've finished writing it.*"

Research participants

Our study included 370 11th grade chemistry major students, who were taught by 21 teachers, and studied toward the matriculation examination. The study population of 370 students included an experimental group (N=271) and a control group (N=99). Students in the experimental group studied the *Taste of Chemistry* module, which emphasized bonding and structure, and organic chemistry in an interdisciplinary context of food. Students in the control group studied bonding and structure, and organic chemistry in the traditional approach without relation to everyday life context and no metacognitive guidance. All the experimental students used the *Taste of Chemistry* module, into which the metacognitive tool was built, so they were all exposed to it via the module.

Research tools and methodology

Research tools included pre- and post-questionnaires. Each contained both close- and open-ended questions. The questionnaires, which assessed students' perceived (PerK) and actual knowledge (ActK), were based on Tamir (1991), who tested students' perception of knowledge using the self-evaluation knowledge inventory questionnaire. In addition, we relied on the assertion of Bandura (1982) that self-perception efficacy influences performance. Based on our theoretical framework, we refer to perceived knowledge as part of knowledge of cognition.

According to Trochim (1999) and Dalgety, Coll, and Jones (2003), a high construct validity of a questionnaire depends on several types of validity, including content, face, criterion, and concurrent validity. While developing the questionnaires, we established construct validity by verifying these validity types. Content validity, which exists if the theoretical constructs are well-defined and comprehensive, was examined by five chemistry and chemical education experts, yielding inter-judge agreement of 90%. Face validity, namely that the questions are good translations of the theoretical constructs, was achieved by using Tamir's questionnaire for concept assignments and our extension of it to comparison assignments.

Criterion validity pertains to meeting the national standards, curriculum and matriculation requirements. This criterion was also checked by the same experts. Concurrent validity, which differentiates between groups, was indeed achieved for both pre- and post-questionnaires and for both types of assignment.

Using a 1-5 scale Likert, we asked the students to indicate their perceived level of knowledge of chemistry before and after studying the *Taste of Chemistry* module by referring to 10 items: five food-related concept assignments and five comparison assignments, which required them to compare between different food-related concepts. Two of the five concept assignments (amino acid and boiling point) and two of the five comparison assignments (solubility in water and the boiling points) were included in the learning materials that both the experimental and the control students studied.

Students who avoided marking their level of knowledge for an item scored zero for that item. Our assumption was that explaining a concept is less complex than responding to a comparison assignment, which requires higher level of thinking beyond understanding and lower level application (Dori & Hameiri, 2003). Accordingly, the students were next asked to choose and explain the meaning of one of the five concepts – a lower level assignment, and to select and respond to one of the five comparison assignments – a higher level assignment.

The following variables were used for analyzing students' responses.

Perceived knowledge (PerK) – the student's ranking (using 1-5 scale) of the chosen concept or comparison assignment he/she chose to respond.

Actual knowledge (ActK) – the score of the student's answer to the chosen concept or comparison assignment, as determined by the sum of scores of three aspects: subject matter knowledge, depth of explanation, measured by the number of chemistry understanding levels used, and interdisciplinarity, measured by the number of disciplines – chemistry, biochemistry, human body, and nutrition – included in the answer (Table 1).

Chemistry understanding levels – macroscopic, microscopic, symbol, and process levels. This variable is a number between 0 and 3 (nobody has ever used four levels) a student incorporated into her/his response.

Concepts from the questionnaires included triglyceride, amino acid, and boiling point. Comparison assignments require higher order thinking skills. Comparison skill in chemistry is the ability to compare and contrast two substances or chemical phenomena. This skill is essential from both the social and the psychological perspectives (Festinger, 1954; France-Kaatrude & Smith, 1985). In science education, comparison skill was researched about 50 years ago (Hungerford, 1969; Hungerford & Miles, 1969), but it has not been directly emphasized since then.

Examples for comparison assignments in our questionnaire included comparisons between oil and fat, between glucose and sucrose, and between boiling points of different substances. The 'boiling point' concept, and the 'boiling points' comparison, are not food-related items and were related to the 'bonding and structure' topic, which had been taught before the students learned the *Taste of Chemistry* module. The reason for including them was twofold: (a) in the pre-questionnaire, the students were given the opportunity to answer questions on topics they already knew, and (b) in the post-questionnaire, the control group students, who had not learned a food related chemistry topic, could get equal opportunity to show their knowledge. Both concepts explanation and comparison assignments were used for monitoring students' perceived and actual knowledge. Table 1, which is the rubric for assessing students' actual knowledge, lists the categories we used to score students' concept explanations and answers to the comparison assignments, where the maximal score is 5.

In order to design our content analysis rubric of students' answers we used 20% of the filled-in questionnaires. These student responses went through the process of inter-rater judgment in order to make sure that the content analysis is as objective as possible. The raters were the authors of this paper and an additional expert in chemical education. Through this process, we revised our rubric to achieve a consent rate of 85%. Then, the rest of students' answers in the questionnaires were scored independently.

Table 1. Rubric for assessing students' actual knowledge

Score \ Category	Level of subject matter knowledge	Chemistry understanding levels	Interdisciplinarity
0	Incorrect	No reference to chemistry understanding	Relates only to one discipline
1	Incomplete	Based on one chemistry level	Combining two or more disciplines
2	A complete and correct answer	Based on two or more chemistry levels	

Examples of concept explanations and answers to comparison assignments at different complexity levels and their content analysis based on the above rubric are presented in Tables 2a and 2b.

Table 2a. Content analysis of students' explanation to a concept chosen by a student

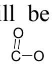
Level of complexity & total score	Example of a student's response and its analysis for the chosen concept: *Triglyceride*
High 5/5	Triglyceride is produced by a compression reaction between 3 fatty acids and glycerol. The fatty acids can be identical or not. At the end of the reaction, three H_2O molecules are released, and we will be able to recognize the esteric bond which looks like this:  Triglycerides in the blood can cause health problems - Level of subject matter knowledge – Complete. The student relates to the reaction between fatty acids and glycerol to different types of triglyceride and to the esteric bond (score 2). - Chemistry understanding levels – the answer involves three chemistry levels: microscopic, symbol, and process (score 2). - Interdisciplinarity – The student relates both to chemistry and health (score 1).
Low 2/5	*A triglyceride is built of three fatty acids and glycerol.* - Level of subject matter knowledge – Incomplete. The student relates to the fatty acids and glycerol, but not to different types of triglyceride and to the esteric bond (score 1). - Chemistry understanding levels – Based on the microscopic chemistry understanding level only (score 1). - Interdisciplinarity – The student relates only to one discipline (Score 0).

Table 2b. Content analysis of students' answers to the comparison assignments

Level of complexity & total score	Example of a student's response and its analysis for the chosen comparison: *What is the difference between oil and fat?*
High 5/5	*Oil is liquid and fat is solid at room temperature. They are both composed of fatty acids, but they differ in their inter- and intra-molecular bonds. Fat is composed of a lot of saturated fatty acid with no double bonds between the carbons; oil is composed of unsaturated fatty acid that has double bonds between the carbons. The double bonds in the molecule affect the spatial structure of the molecule and cause the molecules to be less dense and the van der walls bonds between the molecules to be weaker. This is the reason why it takes less energy to break the bonds between the molecules of the oil and why oil is liquid at room temperature. Oil is healthier than fat because it does not build up in the blood and does not raise the cholesterol level like fat does.* - Level of subject matter knowledge – Complete. The student relates to differences and similarities of structure, bonding and their implications on their state of matter (score 2). - Chemistry understanding levels – Based on three chemistry understanding levels: macroscopic, microscopic, and process (score 2). - Interdisciplinarity – The student relates to chemistry and health (score 1).
Low 2/5	*The difference is in their melting point temperature. Fat has a higher melting point, and this is the reason why it is solid at room temperature and oil is a liquid at room temperature. Fat has a high level of saturated fatty acids.* - Level of subject matter knowledge – Incomplete. The student relates only to the difference and only to the aspect of state of matter. The student does not relate to similarities and differences of both the structure and the bonding (score 1). - Chemistry understanding levels – Based on the macroscopic chemistry understanding level only (score1). Interdisciplinarity – The students relates only to one discipline (score 0).

Findings

The findings section describes the perceived (PerK) and actual knowledge (ActK) and the application of the various chemistry understanding levels in the students' responses.

Table 3 shows that for the concept explanation assignment, the net-gain of the experimental group was significantly higher than that of the control group in PerK and ActK. This might indicate that students in the experimental group perceived their knowledge higher than students in the control group and also gained higher scores. In this assignment students in the experimental group were able to regulate their learning and to choose a concept they felt they knew how to explain. Table 3 also shows that in the comparison assignment the ActK net-gain of the experimental group was significantly higher than the control groups. However, no significance difference was found between the experimental and the control groups for the PerK net-gain. The results also indicate that the net-gains in the comparison assignment were lower than the net-gains in the concept explanation assignment. This outcome can be explained by the fact that comparison assignments are in general more complex than concept explanation ones, and therefore they demand higher order thinking skill. Student in the experimental group who learned how to regulate their learning felt less confident with this assignment which matches the lower results in the ActK compared with the concept explanation assignment.

Table 3. Net-gain in the concept explanation and comparison assignments

	Variable	Research group	Net-gain	S.E.	t	p
Net-gain in the concept explanation assignment	PerK	Experimental	0.17	0.07	$t_{(368)}=2.09$	<0.05
		Control	-0.10	0.14		
	ActK	Experimental	0.73	0.06	$t_{(270)}=7.23$	<0.0001
		Control	0.13	0.06		
Net-gain in the comparison assignments	PerK	Experimental	-0.12	0.07	n.s.	
		Control	0.04	0.09		
	ActK	Experimental	0.36	0.07	$t_{(320)}=3.47$	<0.001
		Control	0.02	0.06		

Chemistry understanding levels

In order to analyze the differences between the experimental group and the control group more deeply, we examined students' actual knowledge based on the number of chemical understanding levels they had integrated into their answers. We found that students in the experimental group presented more chemical understanding levels in their explanations to the concept and the comparison assignments than their control group peers. Figures 4a and 4b respectively show the pre-post differences in the percentage of students who used zero, one, or two-three chemical understanding levels in their explanations to the concept and the comparison assignments they had chosen to explain.

Figure 4a presents a decrease from pre to post in using zero or one chemistry understanding level and a parallel increase in the percentage of students who used two or three chemistry understanding levels. The change in the control group was relatively low compared with the experimental group.

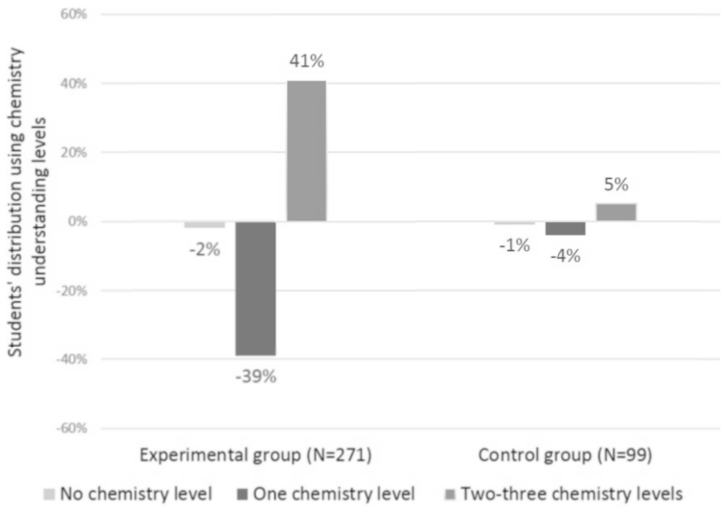


Figure 4a. The change in percentage of students using chemistry understanding levels in their explanation to the concept they had chosen

As noted, the comparison assignment was more complex than the concept explanation assignment. As Figure 4b shows, the percentage of students who switched from using zero or one chemistry understanding levels to two or three levels in their explanations increased by 12% from pre- to post-questionnaires.

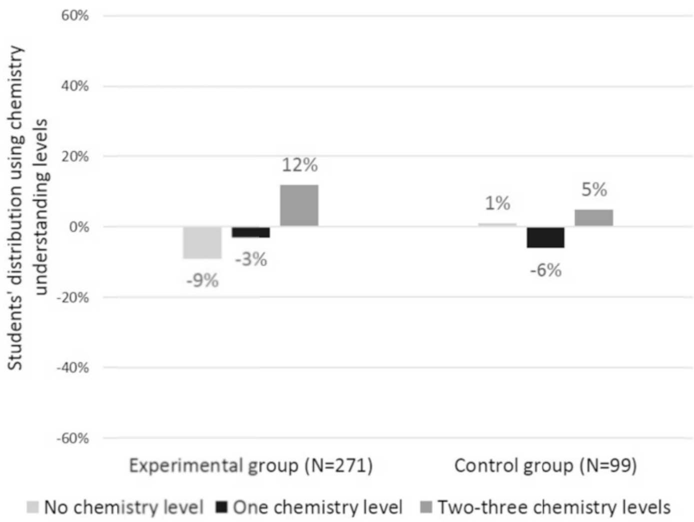


Figure 4b. The change in percentage of students using chemistry understanding levels in their explanation to the comparison assignment they had chosen

DISCUSSION

Veenman and colleagues (2006) emphasized the importance of the relationships between metacognition and cognition while noting that the border between them is fuzzy. They stated that if part of metacognition is the knowledge of a set of self-instructions for regulating student's performance in a specific assignment, then cognition is the tool for gaining the self-instructions. Thus, metacognitive and cognitive activities are circular processes, making it difficult to disentangle them in the assessment of metacognition. Metacognition can sometimes be observed in students' verbalized self-instructions, but when it is not explicitly heard or seen during task performance, it needs to be inferred from certain cognitive activities.

In this research we measured, assessed, and analyzed the variables of perceived knowledge, actual knowledge, and chemistry understanding levels. Figure 5 extends the top part of Figure 1, where we had summarized the theoretical foundations of the research on self-regulated learning. In Figure 5, the double-dash-contoured rectangles symbolize our measured and computed research variables, while single dotted-contour rectangles include explanations of some of the variables and concepts. The large shaded background rectangle represents the use of the metacognitive tool, which encompasses the research variables and pertinent explanations. Motivation is induced by learning in the context of food chemistry. The variable Actual knowledge (ActK) is derived from cognition – the knowledge actually demonstrated by the student. The variable Perceived knowledge (PerK) is derived from knowledge of cognition, which is part of metacognition. It is the student's stated level of knowledge about her/his selected concept definition assignment and comparison assignment. Chemistry understanding levels, which is the number of levels a student incorporated meaningfully into her or his response to the concept explanation or comparison assignment, relates to regulation of cognition.

To determine students' ActK, we assessed the student's learning activity while solving a problem or performing an assignment. With respect to the metacognitive knowledge, PerK, the perceived knowledge, is the level of student confidence while assessing his/her knowledge. In our study, PerK was expressed by the ability to choose the concept or comparison item that can be best explained. Using the metacognitive tool improved students' ability to self-regulate their knowledge and perceive their knowledge levels more precisely, as well as better apply a variety of chemistry understanding levels. As mentioned earlier, experimental students were more motivated than the control peers as a result of learning in context, which explicated the linkage between the subject matter – food chemistry and daily life – food and nutrition. The motivation of the students to learn chemistry was high in the context of food since food is a relevant and interesting topic that is discussed often in the media and among friends.

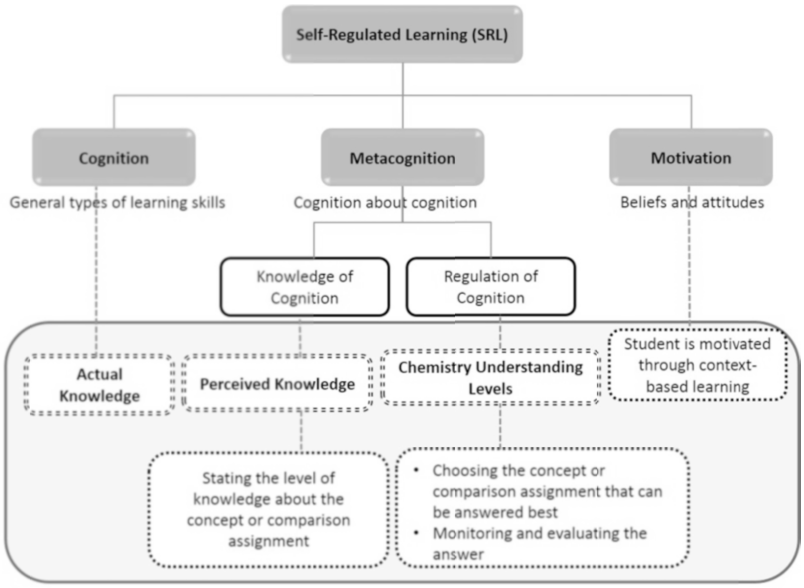


Figure 5. The relationships among the theoretical basis of our study, the research variables, and their explanation

Students in the experimental group demonstrated better knowledge of how to regulate their responses using the metacognitive tool based on the four chemistry understanding levels. Similarly, Kipnis, and Hofstein (2008), who investigated the development of 12^{th} grade students' metacognition in the setting of inquiry based experiments, argued that when students chose the specific inquiry question they can investigate, they in fact exhibited better knowledge.

The regulation process in our study was done in a context-based chemistry environment. In the specific food chemistry domain, students applied their metacognitive knowledge through the use of metacognitive tool, which builds on judicious application of as many of the four chemistry understanding levels as possible. Students indeed self-regulated their learning of the module while making effective use of the metacognitive tool. Caprara et al. (2008) and Bouffard-Bouchard (1990) claimed that self-efficacy and perceived efficacy for self-regulated learning can enhance academic performance. Our findings show similar patterns of students' performance, as expressed in their actual knowledge.

This conclusion is also supported by the pre-to-post increase in the number of chemical understanding levels that the experimental students incorporated into their answers in the concept explanation assignment. The large and significant increase in the percentage of experimental students, who switched from integrating zero or one chemical understanding levels in their answers to the pre-questionnaire to two or three levels in their answers to the post-questionnaire is a clear indication of their increased understanding of chemistry. This significant learning outcome also indicates that the metacognitive tool, which the experimental students had used while studying the *Taste of Chemistry* module, helped them build more complete and meaningful answers. Additional experiments should be carried out to corroborate this conclusion.

Progress in students' performance of self-regulated learning processes is predicted to improve students' academic achievements (Zimmerman, 2000). We have validated this finding in the context of food chemistry. We found that exposure to metacognitive thinking by applying the metacognitive tool to use different levels of chemistry understanding in order to regulate their knowledge and improve their answers, can help students improve their understanding of food related concepts. Bannert and Mengelkamp (2008) claimed that in order to evaluate the effectiveness of metacognitive instruction there is a need to assess whether the explicit metacognitive skills that were emphasized in the teaching are actually being performed. According to Veenman (2012), even when a student said she or he had applied their metacognitive skill, it does not necessary mean that this was done adequately, and the metacognitive skills can still remain unrevealed (Veenman et al., 2006). Therefore, direct assessment of metacognitive skills needs to be implied from "behavioral consequences." Furthermore, Veenman (2005; 2012) has claimed that metacognitive knowledge does not always predict learning outcomes. In our research we asked students to think about their knowledge and state the level of their knowledge. Effectively, we asked them to exhibit their knowledge through answering the question for which they had just assessed their level of knowledge to carry out the required concept explanation or the comparison. This way, students were able to apply their metacognitive knowledge in order to better predict their level of answer and monitor it.

Learning chemistry in context and the metacognitive tool were both important factors in increasing students' chemical understanding. These aspects made chemistry leaning more relevant since it provided meaningful and daily life situations to support the application of science in the students' future. It fulfilled student's personal interest as well as the educational need to become self-regulated learner. Furthermore, the context-based environment encouraged students to be more aware of their health and nutritionial choices. This is important for operating in the society and for making the learning more relevant (Stuckey et al., 2013). The instructions embedded throughout the learning module encourage teachers to explicitly relate to the metacognitive thinking process in answering open-ended chemistry questions. Furthermore, through nation-wide professional development programs, teachers grew professionally and applied the metacognitive tool, resulting in increase of their students' academic achievements (Avargil, Herscovitz, & Dori, 2013; Barnea et al., 2010).

CONCLUSION

Our metacognitive tool can serve as a generic scaffold for constructing and improving teachers' and students' knowledge. Further study should investigate both teachers and students and establish (1) the extent to which students' high achievements and increased deep understanding of chemistry through adoption of the metacognitive tool persist; (2) the extent to which teachers adopt and implement the metacognitive tool not just in chemistry but in other science domains; and (3) how our results and future ones can be extended and generalized to foster incorporation of knowledge of self-regulated learning, including cognition, metacognition, and motivation, into science education in order to further improve both academic and affective outcomes of future generations of students.

Last but not least, we recommend several guidelines for teachers.

Concept- or content-related tips

- Enter the class, understanding that the new learning units are interdisciplinary in nature. Do not teach them in the familiar disciplinary teaching format.
- Understand the importance of these learning units for promoting students' higher order thinking skills as a way to deepen your students' chemistry understanding.
- Get used to reading information on nutrition, environment, high-tech industry, and related societal issues from various sources in order to broaden your knowledge base. This will enable you to conduct better discussions in class, integrating chemistry concepts and processes with global, social, and personal issues.

Pedagogical tips

- Do not assume that your students are familiar with certain thinking skills since they studied them in other disciplines, e.g., that they have graphing skills because they used graphs in mathematics. Integrate assignments that promote these skills into your teaching as much as you can. Tell your students explicitly what are these skills are or ask them to identify which skill(s) is (are) needed for solving a certain problem.
- Apply small group activities or online activities instead of much of your lecturing. These approaches encourage the students to discuss the meaning of the concepts involved in the subject matter or solve problems on their own. By doing so, they build and deepen their chemistry understanding.
- Use molecular modelling tools as much as possible. Do not enter the class without them.

Metacognitive tips

- Use clear and detailed rubrics to assess your students' responses to open-ended questions.
- Share these rubrics with your fellow teachers to validate your assessment criteria.

- Share these rubrics with your students to help them monitor their own learning.
- Serve as a role model to your students by explaining aloud how you think; for example explain how you assess which chemistry understanding levels are required to solve a certain problem.
- Encourage your students to be self-regulated learners by teaching them how to plan and monitor their own learning, how to estimate how much time they need to be well prepared for an exam, etc.

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SIBEL ERDURAN AND AYBUKE PABUCCU

8. PROMOTING ARGUMENTATION IN THE CONTEXT OF CHEMISTRY STORIES

Argumentation is a key aspect of chemistry and should be part of teaching and learning of school chemistry. Argumenation is about providing claims with justification and evidence. Suppose we make a claim about the particulate nature of matter: How do we know that matter consists of particles? What is the evidence? How do we know how to select which evidence? Such questions are highly relevant to chemistry. Yet, if we go into regular classrooms, it is unlikely that students would be engaged in the type of reasoning where they are not only learning about the claims made in chemistry (such as matter is made of particles) but also about how to generate, evaluate and use evidence in justifying those claims. Since the mid-1990s, some science education researchers have been investigating strategies to make argumentation a part of teaching and learning. There is now substantial amount of research that has given us some useful clues about how to structure science lessons and professional development provision for science teachers to enhance argumentation in the classroom. The majority of these researchers have suggested that participation in argumentation develops students' communication skills, metacognitive awareness, and scientific literacy. In addressing some of the challenges that students and teachers face in engaging in argumentation, we designed a series of teaching and learning resources. We have infused argumentation practices such as using evidence in a set of activities aimed at helping students to understand chemistry in the context of motivating stories. We will describe some example activities and research studies where we have trialed these activities to investigate their effectiveness in generating quality arguments in group discussions.

INTRODUCTION

In this chapter, we present research on argumentation in chemistry teaching and learning, and explore some examples. The research contexts in science education relate to the epistemic and narrative practices of science. Epistemic practices are the cognitive and discursive activities that develop epistemic understanding or understanding of how scientific knowledge is developed. In other words, they are activities that engage learners in questioning the nature of chemical knowledge, for instance, why should we believe in this piece of knowledge and not another? How is knowledge justified? What evidence can we use to show that knowledge is

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reliable? These practices thus include holding claims accountable to evidence. Argumentation is an example of an epistemic practice in science. On the other hand, narratives are the oldest and most natural and powerful formalism for storing and describing knowledge. Human beings tend to think in narrative form and our most memorable experiences are held in mind as narratives. Hence teaching science through narratives is likely to help students learn effectively. Engaging students in argumentation serves several purposes. First, it gets them to appreciate the nature of chemistry, for instance, how evidence and justifications are used by chemists to validate chemical knowledge. Second, the skill of argumentation itself can have wider ranging implications on students' everyday lives. Imagine a member of the public who is faced with countless issues that demand the evaluation of claims and evidence, for instance, claims being made about issues that relate to chemistry too, such as climate change, genetic cloning and nuclear energy. Understanding how arguments work is not only a skill necessary for chemists but it is also relevant for general citizenship where an individual is faced with pressing issues in their everyday lives.

Argumentation involves the coordination of evidence and theory to support or refute an explanatory conclusion, model or prediction (Toulmin, 1958). Jimenez-Aleixandre and Erduran (2007) describe the relevant key contributions of argumentation in science education in terms of the following: (a) making public and modelling cognitive processes, (b) developing communicative competences and critical thinking, (c) enculturation into scientific culture, developing epistemic criteria, and (d) developing reasoning and rational criteria. These contributions can be drawn from a set of theoretical perspectives including theory of communicative action, epistemology, developmental psychology, and linguistics. Thus, argumentation can be related to science education broadly and to chemistry more specifically. The focus of argumentation in chemistry education can potentially be on the linguistics aspects of argument construction in chemistry. Alternatively it could be on the cultural aspects and norms of argumentation such as respecting evidence and listening to alternative points of view.

Contemporary policy documents around the world are now promoting the use of argumentation in school science. Consider, for example, the *Next Generation Science Education Standards* (Achieve, Inc., 2013) in the USA which follow earlier calls from the National Research Council (2000) to engage learners in active learning strategies such as argumentation. Research in science education has also placed a strong emphasis on argumentation given the number of papers in key journals on this theme (Erduran, Ozdem, & Park, 2015). There is now a large body of research literature on the topic which the readers can access (e.g. Cetin, 2014; Erduran, 2012, 2006; Erduran & Jimenez-Aleixandre, 2012, 2007; Driver, Newton, & Osborne, 2000; Kaya, Erduran, & Cetin, 2012; Zembal-Saul, 2009; Zohar & Nemet, 2002).

Despite the wealth of research on argumentation in science education in general, the focus on the professional development aspects have been relatively scarce (Erduran, 2006; Zohar, 2008). A significant line of work relies on models of professional development based on Lee Shulman' notion of teachers' pedagogical content knowledge (e.g. Van Driel, De Jong, & Verloop, 2002). Other approaches to teacher education have extended the work of educational psychologists such as Diane Kuhn in application to science education (e.g. Zohar, 2004). In the context of argumentation, advocates for effective professional development have argued that the teaching of argumentation requires a model of pedagogy that is based on knowledge construction as opposed to knowledge transmission (Simon & Maloney, 2006; Zohar, 2008).

There are now some resources for professional development that researchers and teacher educators can draw on to supplement teachers' experiences in argumentation. Professional development in argumentation in science education has been part of some recent European Union funded projects – e.g. the S-TEAM (www.apisa.co.uk) and Mind the Gap Projects (Erduran & Yan, 2010). The "*Mind the Gap: Learning, Teaching and Research in Inquiry-Based Science Teaching*" infused ideas about argumentation into professional development of science teachers, and the project team used an evidence-based approach applying some of the key outcomes of research on teacher education. For example, the work of Supovitz and Turner (2000) guided a model of professional development that engaged participants in inquiry, questioning and experimentation in a collaborative manner. Furthermore, the project relied on the principles of teachers' collaborative exchanges with peers and reflective inquiries into their own teaching. The workshops promoted the teachers' sharing of lesson resources, debate and discussion, and reflection on their own design and implementation of argumentation-based activities. The professional development aspects of the project were summarised in a DVD (Erduran & Yan, 2010), where clips focus on how teachers addressed the curriculum policy context and strategies used to support professional development such as evaluating and reflecting on peer teaching.

Argumentation can be incorporated into chemistry lessons in numerous ways although in the related literature, there are few studies investigating the contribution of argumentation in chemistry education (e.g. Erduran & Villamanan, 2009). Aydeniz and colleagues (2012) explored the impact of argumentation-based instruction on college students' conceptual understanding of properties and behaviors of gases. The sample was 108 students drawn from two general chemistry college courses. The results of their study showed that argumentation-based learning had a positive impact on students' conceptual understanding of the properties and behaviors of gases. This result is consistent with some previous studies that report the positive impact of argumentation on student learning in other contexts (e.g. Jimenez-Aleixandre & Pereiro-Munoz, 2002; Zohar & Nemet, 2002). Cetin (2014) examined the effects of argumentation-based chemistry lessons on pre-service science teachers' understanding of reaction rate and quality of their argumentation. She found that pre-service science teachers' understanding improved in terms of both the context and the quality of argumentation after the intervention. Walker and colleagues (2012) developed an instructional model called Argument-Driven Inquiry (ADI) to promote student engagement in processes of scientific argumentation. In the sections of introductory college chemistry, they compared their model with a traditional approach to address students' conceptual understanding of chemistry, ability to use evidence and reasoning to support a conclusion, and attitude towards chemistry. At the end of the study, they observed significant differences between instructional approaches on measures of students' abilities to use evidence and reasoning while no significant differences in conceptual understanding was observed.

RESOURCES TO SUPPORT ARGUMENTATION IN CHEMISTRY LESSONS

We developed a set of resources to support the incorporation of argumentation in chemistry lessons (Erduran & Pabuccu, 2012). The resources were part of a set of activities that have been featured by the Royal Society of Chemistry, and funded in collaboration by the Training and Development Agency for Schools in the United Kingdom and the Turkish Higher Education Research Council in Turkey. Unlike regular chemistry activities, the activities are not only aimed at helping students understand chemistry concepts, but also to develop their ability to reason with evidence and justifications. Furthermore, each activity was situated in a narrative where the students would see the broader social and cultural relevance of the chemistry topic covered. In the rest of this chapter, we will review some of the activities in detail and illustrate how we tested them in everyday classrooms where the teacher did not undergo any special training. Hence the results of our investigations are likely to be quite typical of other science teachers' implementation of activities without any professional development intervention.

We will give examples of three activities. The first two activities are about the behaviour of gases and they are aimed at secondary chemistry education. Many studies reported that secondary students have difficulty in understanding gases concepts (Benson, Wittrock, & Baur, 1993) because of the abstract nature of the concept and inappropriate daily life explanations (Cetin, Kaya, & Geban, 2009). Stories were used in both activities to help students to link chemistry knowledge to everyday life contexts. For the third activity, we used figures and graphics, instead of a story to promote students' argumentation. The activity was about conformations of alkanes and it was developed for engaging university students in the argumentation process. University students have a great deal of difficulty in understanding the concepts of organic chemistry (Krylova, 1997). The reasons for student difficulties in organic chemistry are varied but one of the major problems with university students in learning organic chemistry is that they tend to resort to a memorization-oriented approach to learning (Duffy, 2006).

For all activities, the students were expected to work in small groups to complete writing frames which were designed to structure their written arguments. Audiotape recorders were placed at the table of the groups to capture group talk. All audiotapes were transcribed and analysed to determine the nature of group argumentation. The data analysis was conducted separately by two researchers. Any disagreement arising during the analysis was resolved through discussions.

For assessing the quality of argumentation, we traced the instances where students expressed points of view that were clearly against each other. Then, we used the analytical framework developed by Erduran and colleagues (2004) to evaluate the arguments. These researchers classified the argument level from 1 to 5. For instance, when there was opposition between students but the opposition consisted of only counter-arguments that were unrelated and had no data or warrants to back up the claims, they coded the argumentation as a level 1. When the argumentation has arguments with a series of claims or counter-claims with weak rebuttal as well as data and warrants, they labelled it as level 3. In our study, we traced the level 3 or higher level oppositions and we coded these oppositions as a rebuttal. From the perspective of Toulmin, rebuttals indicate the exceptional circumstances under which the claim would not be true (Erduran, Simon & Osborne, 2004). Moreover, arguments that include rebuttals are a measure of conversational engagement (Erduran et al., 2004). Thus, in our study, we mainly focused on the rebuttals in the transcripts. Subsequently, we investigated the nature and accuracy of the rebuttals in the transcripts.

Activity 1: Halloween Crush!

The key concepts in this activity are gas behavior and air pressure (Figures 1, 2, 3). The topics are situated in a narrative about some strange incidents that occurred when a group of students were having a party during Halloween in a chalet in the mountains. The students hear a bang in the kitchen and discover that the lid of an oil can popped when heated. The data presented here were drawn from the two classes of 9th grade high school students. There were 31 girls and 16 boys in a total of 10 groups. The age range of the students was 15-16 years old. The students were randomly assigned to groups of 4 and 5. The activity lasted for two class hours devoted to gases. The participants all attended chemistry classes taught by the same teacher with 18 years of experience. The school was a special public high school in a medium-sized town in Turkey. The teacher did not receive any professional development or training on argumentation, and generally the students and the teacher were not familiar with argumentation. In this activity, students were asked to evaluate through discussions in small groups the plausibility of the different evidence cards for why the lid of the oil can to shoot off when heated and why an oilcan collapses on itself when it's subsequently left to cool off. Furthermore, the students were asked to make a prediction about what would happen if the lid of the oil can was not closed after it was removed from the oven (i.e. would it collapse again or not?).

Table 1 illustrates the frequencies of the rebuttal codes for the 10 groups. As seen in the table, each group had different number of rebuttals. The highest number of rebuttals was observed for group 4 and group 8. The students in these groups also gave more examples from daily life to support their claims or disprove the others' claims. The data suggest that these groups were highly engaged in the argumentation process.

Table 1. Frequency of the rebuttals

Number of the	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
Rebuttal	3	1	2	13	2	6	3	12	10	1
Wrong Rebuttal	1	1	2	5	2	3	2	5	5	-
Link to Everyday (LE)	1	-	3	10	1	2	-	5	2	1
Wrong LE	0	-	1	6	1	2	-	3	2	1

TEACHER OUTLINE

This activity presents a set of alternative explanations about strange incidents that occurred when a group of students were having a party during Halloween in a chalet set in the mountains. Students are asked to evaluate through discussions in small groups the plausibility of the different explanations for why the lid of oilcan to shoot off when heated and why an oilcan collapses on itself when it's subsequently left to cool off. Furthermore, the activity immerses students to generate their own explanations to account for the observed phenomenon.

The aims

The aim of this exercise is to evaluate different theories for what causes the can to collapse and the lid to shoot off. Students will be required to justify with reasons their choice of claims and also justify with reasons why they do not agree with other claims.

Learning goals

The learning goals of this activity are for students:
- to learn to evaluate arguments and provide justifications for what they believe in;
- to provide justifications for why they think alternative arguments are not plausible;
- to evaluate alternative explanations and reasons
- to think about the language they use, whether their reasoning is clear, and whether it justifies their conclusion

Teaching points

For this activity students will need to know about the air pressure and the behaviour of gases. Also they need to know how to express their ideas in words.

Teaching sequence

- Distribute the activity sheet and explain the task.
- Probe the students' understandings of air pressure and the behavior of gases through a brain storming session. This should take about 10 minutes.

- Now explain that the pupils will need to assess the explanations for the strange incidents that occurred in the chalet from the table on the sheet and give reasons why they think the observations took place. They will also need to create their own explanation about the situation. Ask the students to get into groups of 4 or 5 and discuss each explanation together before putting their responses in the boxes on the sheet. Allow about 20 minutes for the group task.

Finally conduct a plenary of the results from all the groups. There is a class discussion at the end so ask who would like to argue for the explanation. Then ask who would like to argue against it.

Figure 1. Teacher outline for the Halloween crush activity resource

SCENARIO

It was unusually cold Halloween day. It was freezing and snow covered the ground. Because of the heavy snowstorm, a few teenagers who rented a chalet to have a Halloween party were stuck in the chalet. Teens did not care much about this unusual snowstorm because they had brought a lot of food and drinks with them. They started to prepare a big Halloween supper for themselves but after a while they realized that they had not broutgh any oil or butter with them. Because the chalet had not been used for a long time, in spite of their detailed inspection they just were able to find one empty olive oilcan in the kitchen. They were little upset for this situation. They stopped preparing supper and they just made some cold snacks and sandwiches to eat in front of the fireplace. When they told horror stories each other, there was only Jane in the kitchen. After a while, Jane's screaming was heard from the kithchen. When teens run over the kitchen, they found Jane frightened. But a few seconds later when she saw their friends' faces, she burst into laugh and she cherrfully started to explain what happened in the kitchen. She said she realized some freezed olive oil at the bottom of the can and to take this freezed oil out, she started to heat the can at the oven. However few minutes later, because the cover of the can abrubtly bursted with loud noise she got frightened and screamed. By this means, teens relaxed with her explanation. Eddie holded the oil can with a piece of cloth and removed it from the oven. He attentively put the cover on the can and left it in the kitchen. After five minutes, while all teens were in front of the fireplace and they were continuing to tell horror stories, they heard some weird noises from the kitchen. At last when they plucked up the courage to go to the kitchen, they found nobody in the kitchen but the oilcan had been still crushed noisily by itself. Teens hugged each other for a while. At the moment Philips remembered their chemistry lessons and he explained what had happened in the kitchen by using his chemistry knowledge.

Figure 2. Scenario for the Halloween Crush activity resource

STUDENT EXERCISE

In the table that follows, some explanations are given. Decide which of the explanations Philips could have used to explain the lid was thrown off.

The reason of bursting of the lid was…	Our explanation
increasing inside pressure of the can	
increasing volume of the gas molecules in the can	
increasing speed of the gas molecules in the can	
increasing impact of gas molecules on the can	
hot air raises	
the inequality of the pressure inside the can & the air pressure	
the expansion of the can by heating	

Our explanation about the reason for why the lid burst.

Below are some explanations about why the oil can crushes by itself. Decide which of the explanations Philips could use.

Oilcan crushed because of…	Our explanation
the power of air pressure	
no gas molecule inside	
the number of gas molecule insde decreases	
the volume of gas molecule inside decreases	
the speed of gas molecule inside decreases	
the volume of the can decreases	

Our explanation about the reason for why the oil can crushes by itself.

What would happen if Eddie had not closed the lid of the olive oilcan after he had removed it from the oven?

If the lid of the can was not closed…	Our explanation
the shape of the can would not be changed	
the shape of the can would increase because more molecules would enter the can	
the can would crush by itself again	

Our explanation for what would happen if Eddie had not closed the lid.

Figure 3. Student exercise for the Halloween Crush activity resource

The following excerpt included the conversations among students about the reason why the oil can collapsed on itself and also it contains a rebuttal.

Student 1: Oil can crushed because there were no gas molecules inside.
Student 2: There must be some molecules inside. There should be.
Student 1: But if it was open? If the lid was not covered, there would be no gas molecules inside. Come on. If we put a box here, there wouldn't be any gas molecules inside?
Student 2: Yes, there should be.
Student 1: So there is always gas pressure inside.
Student 1: Ok, you are right.

One student gave an example from daily life by saying that "if we put a box here". Most of the time when the students disagreed with the others' claims, they attributed their claim to the daily life examples, the teacher or the textbook. However, sometimes students' rebuttals indicated their misconceptions about gas behavior (see Table 1 for frequency of instances).

In total, there were 53 rebuttals for this activity. Table 2 presents the frequencies of the rebuttals for the different claims. The students usually argued with each other about how the number of gas molecules changes in the oil can in different circumstances.

Table 2. Frequency of the rebuttals for different claims

Claim was about ...	Number of rebuttals
the number of gas molecules inside	16
the power of air pressure	9
the volume of gas molecules	9
the kinetic energy or speed of gas molecules	9
the structure of the oilcan	10

Other data around this activity relate to the use of everyday life examples during students' discussions. There were a total of 25 different daily life examples. 22 of them were for the second question (i.e. the reason for the collapsing of the oil can). As illustrated in Table 1, 16 instances used scientifically incorrect statements to support claims. Moreover, we found that the daily life examples were used to convince the other students who even had the scientifically correct idea. For this activity, everyday life examples were used relating the number of gas molecules (5 instances), the volume of gas molecules (4 instances), the expansion of the substances (7 instances) and so on. Following excerpts presents one of the daily life examples used in the argumentation process. The plastic bottles and the telephone cables were the most popular objects that students referred to in terms of links to everyday life.

"The volume of the molecules in the oil can decreases with the decrease in temperature" (Evidence card statement)

Student 1: *Perhaps.*
Student 2: *The volume has nothing to do with temperature.*
Student 1: *Didn't you come to…When I stayed in the dormitory, whenever I went out to get water, the bottle in my hand would shrink. I think that has something to do with the change in heat and volume too.*
Student 2: *What are you saying?*
Student 1: *Increase or decrease in volume are different things.*
Student 2: *No, I'm trying to say this. Look, you are describing your experience. If that plastic bottle can shrink, then the oil can can too. I am thinking that there is something like that.*

Activity 2: Holiday in Dubai

The main purposes of this activity are (a) to provide a context for the students to generate arguments about the behavior of gases using evidence; and (b) to consider the evidence for the gas laws, the constant pressure vessels (balloon) and the constant volume vessels (crystal ball) (Figures 4, 5, 6). The activity was implemented one week after the first activity with the same students and the same teacher. Here, we present the analysis for the data from 9 groups for which there was a complete data set. This activity requires students to evaluate the evidence presented on the cards to (a) construct an argument about the reason why a balloon exploded when it was taken outdoors; (b) to predict how the pressure and the volume of the balloon (0.5 mole air) changes outdoors and then indoors but adding 0.5 mole of air; and (c) to predict what would happen if a crystal ball consisting of 0.5 mole air was taken outside and then indoors but adding 0.5 mole of air. The students discussed these three questions in small groups. Here, we counted 36 rebuttals in total. The number of rebuttals for three questions were 6, 13 and 17, respectively. The students spent most of the time arguing about the second and third questions. For these questions, students would need to know about constant pressure and volume vessels. However, they did not realize that the balloon is an example for the constant pressure vessel, and the crystal ball is an example for the constant volume vessels. Instead, they tried to answer these questions just by using ideal gas law ($P \cdot V = n \cdot R \cdot T$). The following example was about the third question.

Student 1: *What a minute, if the number of moles increase, the pressure increases too.*
Student 2: *Yes.*
Student 1: *We said, if the number of moles increases, volume increases; if the volume increases, the pressure decreases.*
Student 2: *Those are directly proportional.*
Student 1: *I said to you, pressure…*
Student 2: *Never mind, let's not change it.*
Student 1: *Didn't we say if the number of moles increase, the volume increases?*
Student 2: *One thing is inversely proportional, P and V.*
Student 1: *We said if the volume increases, the pressure decreases. In this figure here…*
Student 2: *Is only P inversely proportional to V?*
Student 3: *Didn't I say at the beginning that volume doesn't increase with pressure?*
Student 1: *It's directly proportional with V though.*
Student 2: *We'll change it then.*
Student 1: *No. I think that's right. We are not getting something here.*
Student 2: *Couldn't the teacher give us the wrong card?*
Student 1: *Maybe we are interpreting this wrong.*
Student 2: *Is volume directly or inversely proportional?*

Student 1: Volume, pressure inversely.
Student 2: How come, then, the number of moles is directly proportional?
Student 1: No, I think that was right. We are not getting something here.

TEACHER OUTLINE

This activity requires students to use and evaluate evidence presented on cards to (a) construct an argument about the reason why a balloon exploded when it was taken outdoors and (b) to evaluate critically the arguments of other students. The students are asked to work in groups.

The aims

The purpose of this exercise is to:
1. provide a context for students to generate arguments about behaviour of gases using evidence
2. to consider the evidence for the scientific conception of gas laws.
3. Learning goals
4. The learning goals of the activity
5. provide an opportunity to consider and evaluate evidence
6. generate an explanation for what happens when the balloon was taken outdoors
7. consider and evaluate the arguments of other students
8. to have an opportunity to evaluate claims presented in the evidence cards

Teaching points

Students will need to have some understanding of gas laws and air pressure. The alternative explanations produced by the students will provide a context for argumentation. For example, one explanation could be that the balloon exploded when it was taken outdoors because when the temperature increases, gas molecules expand. The scientific explanation is that the kinetic energies of gas molecules are directly proportional with their temperature in Kelvin. In this case, we would expect the pressure of the balloon rise with increasing temperature. To decrease the pressure, the balloon increases in volume but if it is not possible to expand, it will explore because of the inequality between the pressure in the balloon and the air.

Figure 4. Teacher outline for the Holiday in Dubai activity resource

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STUDENT EXERCISE

Jon and Frances, who went to Dubai for a holiday, got exhausted from heat since the outside air temperature was 50ºC. They went into the shopping centre, where air temperature was maintained at 25ºC. After they spent some time at the mall, Jon found two similar balloons left after a store opening. He gave the more bloated balloon (containing 1 mole of air) to Frances and kept the other (containing 0.5

mole of air) himself. Even though Frances was glad about this gesture, when they went out Frances' balloon exploded. Jon's balloon expanded and looked really beautiful. Hence, she was angry with him but in this situation there was something about chemistry that she forgot to take into account. Jon realized this fact and offered her to return to the mall and explain what happens
You can use the evidence cards to explain the questions below. Write down the number of each used card according to the order of importance.
Why did France's balloon explode but Jon's balloon did not when they went outdoors?

Evidence cards

First draw Jon's balloon in the mall. Then draw the balloon outdoors and draw the balloon indoors but consisting of 1.0 mole air. Take into account the possible changes in volume (V) and pressure (P) that occur in the balloon.
If they bought a crystal ball, which consisted of 1.0 mole air, what would happen to the crystal ball when they took out it outside? (i.e., pressure, volume)

Evidence cards

Figure 5. Scenario for the Holiday in Dubai activity resources

Evidence cards:
1. Gases fill any container that they occupy
2. Gases have very weak intermolecular forces
3. Gas molecules expand when heated
4. The pressure of container having a piston is always equal to the air pressure
5. Air pressure changes with temperature
6. The kinetic energy of gas molecules is directly proportional to temperature
7. If the gas filled container having a piston is heated, it's volume will expand
8. At constant temperature, the volume of a container having piston increase with the number of molecules in it.
9. In a fixed volume container, increasing the number of gas molecules increase the total pressure.

Figure 6. Evidence cards for the Holiday in Dubai activity resources

In this episode, the students thought that if the number of moles increases, the pressure also increases because moles is directly proportional to pressure (i.e. $P \cdot V = n \cdot R \cdot T$). Also, the number of moles is directly proportional to volume. So, both the volume and the pressure should increase. They could not relate to the fact that the volume is inversely proportional to pressure.

Although this was the second argumentation activity for the students, the number of rebuttals was lower than that the first activity. This is probably because students did not have much prior knowledge about the constant volume and the constant pressure vessels. However, the authority (i.e., the chemical formula written in the textbook) and the daily life examples were important sources for their rebuttals. Furthermore, for the first activity, the students mainly talked about the reason why the oil can collapsed on itself (i.e. second question) because they were really interested in it. A lot of students asked their teammates if they had seen it before or they wished their mom let them to try it at home. The data suggest the importance of attracting students' attention in getting them to engage in argumentation.

Activity 3: Alkanes in Stress

Arguing about some science topics like organic chemistry would seem more difficult than other topics because organic chemistry learning is often based on rote learning and memorisation. The activity context is about conformations of alkanes. For the activity, the students need to have some understanding of concepts such as of conformations, Newman projection formula, types of strain, VSEPR theory, hybridization, structural isomers and stereoisomers. This activity requires students to use and evaluate evidence presented on graphs and evidence cards. In the graph, six different conformations of butane and their potential energies are shown. However, only for two of the conformations Newman projection formulas are given in the graph, and students are asked to predict the other four missing Newman projection formulas. Students discuss their observations and try to make prediction based on their observations. Then they compare their observations with their predictions. If they think their prediction is valid, they then need to support their predictions with evidence and they need to produce explanations for their predictions. The learning goals are: (a) to provide an opportunity to consider and evaluate evidence, (b) to generate an explanation for how the energy of the conformation of butane changes for different Newman projection formulas, and (c) to consider and evaluate the arguments of others.

The participants in this activity were 46 second year pre-service science teachers taking an organic chemistry class. The second author was the teacher of the class. The pre-service science teachers were asked to get into groups of 3-5. The groups were observed and audio recorded to investigate the nature of their argumentation. The conformations of alkanes were covered as part of the regular curriculum in the general chemistry course. The activity required pre-service science teachers to use and evaluate evidence presented on graphs and evidence cards. Before implementing the activity, it was unclear how argumentation could proceed in the context of conformations of alkanes because organic chemistry in this program is generally based on rote learning and memorization.

TEACHER OUTLINE

This activity requires students to use and evaluate evidence presented on graphs and evidence cards. In the graph, six different conformations of butane and their potential energies are shown. However, only two of the conformations, Newman projection formulas are given in the graph, and students are asked to predict the other four missing Newman projection formulas. Students discuss their observations and try to make prediction based on their observations. Then, they compare their observations with their predictions. If they think their prediction is valid, they then need to support their predictions with evidence and they need to create explanations for their predictions.

The aims

- provide a context for students to generate arguments about conformations of butane using evidence that they extracted from the graph;
- to consider evidence for the scientific conception of conformations

Learning goals

- provide an opportunity to consider and evaluate evidence;
- generate an explanation for how the energy of the conformation of butane changes for different Newman projection formulas.
- consider and evaluate the arguments of others

Teaching points

Students will need to have some understanding of concepts such as of conformations, Newman projection formula, types of strain, VSEPR theory, hybridization, structural isomer, and stereoisomers. The alternative predictions and explanations produced by the students will provide a context for argumentation. For example, one explanation could be that the stability of a molecule is not changed with the type or amount of the strain that the molecule has. The scientific explanation is that molecules have conformations with high strain as well as conformations with low strain. High strain conformations are when certain parts of the molecule that repel are forced to be close to one another. Molecules, therefore, are more stable at a low strain structure.

Teaching sequence

- Distribute the activity sheet and explain that students will need to observe how the potential energy changes with two different Newman projection formulas of butane at the graph.
- Then ask students to work in pairs to complete the part of a sheet requiring a prediction. They should spend up to 25 minutes to complete the prediction

section of the sheet. Tell the students that each group will need to select a member to present their results to the whole class.

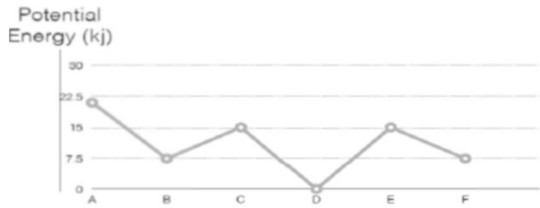
- Conduct a plenary discussion with each group presenting their results. When there are differences between groups, encourage the students to provide justifications for how the other group's point of view is not valid. For instance, ask "does anyone want to suggest why they think that might be wrong?"In other words, encourage them to provide rebuttals to others' arguments.

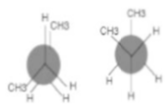
Figure 7. Teacher outline for the Alkanes in Stress activity resources

STUDENT EXERCISE

Question 1

The graph below shows the changes that arise from rotation about the C2-C3 bond of butane. Here are the two Newman projection formulas for the conformations of butane. The other four Newman projection formulas for the conformations of butane in the graph were erased and they replaced with the letters A, B, C and D respectively.





Below are the five different Newman projection formulas. Look at them and try to estimate the erased Newman projection formulas in the graph. Complete the below table and use the evidence from the evidence cards to substantiate your claims.

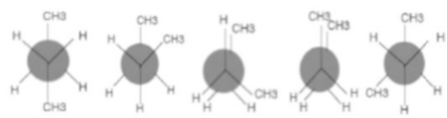


Figure	A/B/C/D/None	Type of Strain	Evidence
I			
II			
III			
IV			
V			

Figure 8. Student exercise for Alkanes in Stress activity resources

EVIDENCE CARDS

- Strain: Energy associated with a system due to its geometry.
- Torsional strain: Destabilization due to the repulsion between pairs of bonds caused by the electrostatic repulsion of the electrons in the bonds.
- Van der Waals strain: Destabilization due to the repulsion between the electron clouds of atoms or groups. This occurs when atoms or groups are too close to each other due to the electrostatic repulsion of the electrons.
- Angle Strain: Destabilization due to distortion of a bond angle from its optimum value caused by the electrostatic repulsion of the electrons in the bonds.
- The different spatial arrangements that a molecule can adopt due to rotation about "s bonds" are called conformations.
- In structural isomers, the atoms and functional groups are joined together in different ways.
- In stereoisomers the bond structure is the same, but the geometrical positioning of atoms and functional groups in space differs.
- Isobutene is more energetically stable than n-butane.
- VSEPR theory is useful to explain the stability of different conformations of molecules.

Figure 9. Evidence cards for the Alkanes in Stress activity resources

The data resulted in 39 rebuttals and one daily life examples in the transcripts. Most of the rebuttals were about the following: the angle strains (10 instances); the relationship between potential energy and stability (7 instances); the eclipsed or staggered conformation (6 instances); the torsional strain (5 instances); and the structural isomer (6 instances). Many rebuttals occurred because the students did not understand the different spatial arrangements that a molecule can adopt. For instance, in the activity, all Newman projection formulas had a tetrahedral shape. So, none of them had an angle strain. However, the students made 10 rebuttals when they discussed if the figure had the angle strain or not. The following is an example for the rebuttal code about the structural isomers:

Student 1: This is not n-butane
Student 2: No, it must be n-butane. Look at the numbers of Carbon. 1,2,3,4,5. There are 5 carbons
Student 1: If we draw n-butane. Look there are 4 Carbon here.
Student 2: Yes, you are right
Student 1: I think it is not n-butane
Student 2: We should link –CH3 to –CH3
Student 1: But there are only three –CH3 here
Student 2: Look these two –CH3 were connected to the same carbon
Student 1: Yes, because of it, it should not be n-butane
Student 2: It must be isobutane
Student 1: It is not a conformation for butane

Student 2: Isn't it?
Student 1: Yes. Look at it

The fact that the organic activity managed to engage students in a discussion is encouraging, particularly considering that in this program organic chemistry lessons generally tend to rely on memorization.

CONCLUSION

We reported on the use of argumentation as a strategy to promote student engagement and reasoning in chemistry. As a critical aspect of chemical reasoning, argumentation instills in learners an appreciation of the nature of chemistry, particularly if it is situated in motivating and interesting stories that can be relevant to the students' lives. Having designed chemistry-specific argumentation activities and tested them, we can outline a set of lessons that we have learned. Students' prior knowledge from their daily life experiences was an important factor for the quality of the argumentation. That is, when there is a claim that conflict with students' current experiences, students made rebuttal(s) to disprove it. Also, we observed that some students misinterpreted the daily life examples that they used to support their claim. Prior knowledge based on authority (i.e., the chemical formula written in the textbook) was also an important source for the rebuttals. For the second activity, for instance, the students mainly attribute their claim to the ideal gas laws.

The use of the story format was useful in helping students to make connections between knowledge about gases and daily life. Especially for the first activity, there were 25 different daily life examples in the transcripts. Although the second activity was also included as a story, just one daily life example was given during the activity. This was probably because the students did not have enough prior knowledge about the constant pressure/volume vessels. We observed that most students memorized the ideal gas equation without understanding gas behaviour. For the organic chemistry activity, the situation was quite different from the others. For instance, the students' prior knowledge from authority and the instances were really low. However, they could make more rebuttals than that of the second gases activity. The most unique feature of the organic chemistry activity was the use of figures and graphics. For organic chemistry students, it was not easy to understand the different spatial arrangements of the molecules and the graphic representations. Hence, most of the time, they discussed about them. The results of the testing of the resources are encouraging given the fact that the teacher who taught the first and second activities was not trained in argumentation. With respect to the third activity, it was also the second author's first attempt at incorporating argumentation in her teaching, although she had been exposed to the theoretical literature in argumentation in science education.

In summary, we have illustrated some example activities where we have promoted the use of argumentation in chemistry lessons. We have illustrated the results on the implementation of these activities in secondary chemistry lessons and preservice teachers' learning at the university level. The activities provide guidelines for incorporating argumentation in everyday chemistry classes. Furthermore, they illustrate how learners' interest in chemistry can be stimulated in the form of stories that have relevance to students' personal lives to the extent that this is possible. Wherever such relevance might be too difficult to establish, for instance in the case of the alkane chemistry, the framework of argumentation can still be functional and useful in getting students to deconstruct ideas through discussion, questioning and reflection. In the sense that argumentation infuses the use of evidence, criteria and justifications to support or refute claims, the examples provided in this chapter can be applied to novel topics and contexts in chemistry education.

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9. CHEMISTRY EDUCATION FOR SUSTAINABILITY

Preparing students to become able shaping their society in a sustainable way makes education relevant for the learner and the society they live in. The idea of education for sustainability offers a justification for focusing the young generation to become responsible citizens and to allow them developing corresponding skills. All learning domains, and thus also chemistry education, are asked to contribute to this goal. In accordance with this idea, the central question of this chapter is: How can teaching and learning of chemistry be structured in-line with the idea of education for sustainability in order to make chemistry education more relevant for the learners and the society in which they live and operate? This chapter discusses theoretical underpinnings of sustainability and corresponding education. It describes the relevance of chemistry for sustainability and presents examples from the chemistry classroom, e.g. chemistry learning embedded in socio-scientific issues (SSI).

INTRODUCTION

Since the report *Our Common Future*, published by the United Nations in 1987, sustainable development has become one of the most frequently used key-terms in political debate. Modern concepts of sustainable development encompass different dimension, among the most prominent are ecological, economic, and social sustainability (Burmeister, Rauch, & Eilks, 2012; Figure 1). All our individual and political actions should be reflected in the light of these three demands. The claim concerns every field of society and thus also chemistry and chemistry education. However the question is still under debate: How can chemistry education contribute best to more sustainability in our society, today and for the future?

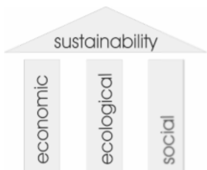

Figure 1. The three pillars model of sustainability (Burmeister et al. 2012)

As with human rights, sustainable development may be regarded as a regulatory idea for policy and individual behaviour (Rauch, 2010). Such ideas do not determine how an object is made up but serve as heuristic structures for reflection. Regulatory ideas give direction to action and learning processes. In terms of education for sustainability, this implies that the contradictions, dilemmas and

I. Eilks & A. Hofstein (Eds.), Relevant Chemistry Education – From Theory to Practice, 163–184.

conflicting goals inherent in this vision need to be constantly re-negotiated in a process of discourse between participants in each and every concrete situation. The goal of sustainability implies a great challenge, but has also considerable potential to offer for enhancing innovative developments in society and also in education. Education is considered to be one of the most important keys for sustainable development, thus making learning chemistry for sustainability relevant for the individual and the society she or he lives and operates in (Stuckey, Hofstein, Mamlok-Naaman & Eilks, 2013).

Like all other domains of education, also chemistry education is challenged by the political agenda of education for sustainability (Burmeister et al., 2012; Jegsted & Sinnes, 2015; Juntunen & Aksela, 2014; Rauch, 2015). The UN world decade of *Education for Sustainable Development* (ESD) just finished in 2014. The decade of ESD was seeking for impacts of chemistry education, among all the educational domains, to contribute to sustainability and preparing the students for this goal. School chemistry education was suggested to promote competencies among the learners to become scientifically literate and also to learn about how to actively participate in a democratic society on questions based on chemistry, science and technology. Chemistry education should contribute to making students capable of understanding and actively participating in societal discourse and decision-making on socio-scientific issues related to chemistry and its manifold applications (Hofstein, Eilks, & Bybee, 2011).

For making chemistry education relevant in the means of education for sustainability, it should be structured to contribute the development of competencies for students understanding and allowing them for participating in societal debate about applications of chemistry and chemical technology. One prerequisite for doing so is that students should gain substantial chemistry knowledge in the context of respective socio-scientific/sustainability issues to understand the underlying developments, alternatives and dilemmas. But, gaining subject matter knowledge alone will not be enough (Sjöström & Talanquer, 2014). The students, as future citizens, also need to learn how societal debate about questions related to chemistry, industry and the environment functions as well as to develop skills to involve themselves together with others in the societal processes of democratic decision making. That should be the focus of relevance-driven ESD-type curricula in science and chemistry education (Eilks, Rauch, Ralle, & Hofstein, 2013).

This chapter will describe the theoretical underpinnings of education for sustainability in general, and concerning chemistry learning for sustainability in particular. Different theoretical frameworks will be introduced for chemistry learning for sustainability based on the idea of *Bildung*, Action Competence, or socio-scientific issues-based science education. Illustrating examples will focus learning about political decision-making, mimicking the authentic societal practice of product testing, or life-cycle analysis in chemistry teaching.

SCIENCE EDUCATION FOR SUSTAINABILITY

We live in a globalized society, characterised by increasing complexity and unpredictable consequences of techno-scientific developments (Ekberg, 2007). The *chemicalisation* of our society and bodies (Casper, 2003) is only one example of the threats to the Earth and mankind that characterizes the contemporary society as a risk society. Education has to react to these challenges in general (Elmose & Roth, 2005), as chemistry education has to do in particular (Burmeister et al., 2012; Sjöström, 2013a). Global environmental issues modern society is faced with are, e.g. climate change, ocean acidification, ozone depletion, decreasing freshwater quality, and the availability and distribution of resources (Rockström et al., 2009). All of these problems concern among others the recent applications of chemistry on the one hand, and on the other hand all of these challenges cannot be solved without innovations in chemistry and technology (Burmeister et al., 2012).

The concept of 'Bildung'

The democratic risk society needs citizens who are able to understand the world and make value-based (and independent) decisions – in their private and professional lives, and as responsible citizens (Elmose & Roth, 2005). Since chemistry is so crucial for many of these developments, all citizens need to be educated at least to a certain extend also in chemistry. However, a societal driven emphasis of the chemistry curriculum is aiming at a broader range of objectives (Eilks et al., 2013). Among the many underlying frameworks suggesting a stronger societal orientation of chemistry education we can allocate the European tradition of *Bildung* (Elmose & Roth, 2005; Hofstein et al., 2011; Sjöström, 2013a). To specify any contemporary meaning of *Bildung*, we have to reflect our presence including the fact of living in a globalised risk society. For Elmose and Roth (2005), who discussed citizen competences needed in the risk society, *Bildung* "*involves competences for self-determination, constructive participation in society, and solidarity towards persons limited in the competence of self-determination and participation*" (p. 21). Elmose and Roth, as well as Hofstein et al. (2011), refer in their understanding of *Bildung* to the German scholar Wolfgang Klafki and his concept of (*Allgemein-)Bildung*. For Klafki any topic believed relevant enough to be taught in formal education should possess relevance for the learner both in present and future. It should evidence potential for raising students' capacities for self-determination, participation in society, and solidarity with others. Biesta (2012a) emphasizes that "*the role of the individual in the process of Bildung*, […] *has to be understood as a reflexive process*" (p. 817), i.e., a process were the individual establishes both a relationship and critical stance towards the existing culture and society for the individuals becoming "*autonomous subjects of action and responsibility*" (Biesta, 2012b, p. 7).

Action competence

The idea of developing individual capabilities for acting in a democratic society is also available from Mogensen and Schnack (2010). They argue for a concept of *Action Competence* that is "*closely linked to democratic, political education and to* […] *the notion of* '*Bildung*'" (p. 60). Action competence is a set of skills for making well-informed decisions (Mogensen & Schnack, 2010). This term has been developed in education and refers to citizens' ability to act at both the individual and societal levels. It can be described in terms of its social, values-based, personal, and knowledgeable aspects.

Action competence is one of several key competences for sustainability. In a literature review on such key competencies, five main competences were identified: systems-thinking competence, anticipatory competence (e.g. time perspectives, including future thinking), normative competence (e.g. ethical concepts), strategic competence (e.g. action competence), and interpersonal competence (e.g. solidarity) (Wick, Withycombe, & Redman, 2011). This analysis corresponds with the KOM-BiNE model of competences that teachers should acquire for becoming able to implement ESD in science education (Rauch & Steiner, 2013; Figure 2). The model is about visioning, communicating, reflecting, knowing, acting, valuing and feeling. Rauch and Steiner (2013) suggest: "*It is only individuals with sufficiently developed strength of self who can act self-confidently on the basis of their own reflection, especially when issues are contradictory and complex*" (p. 14).

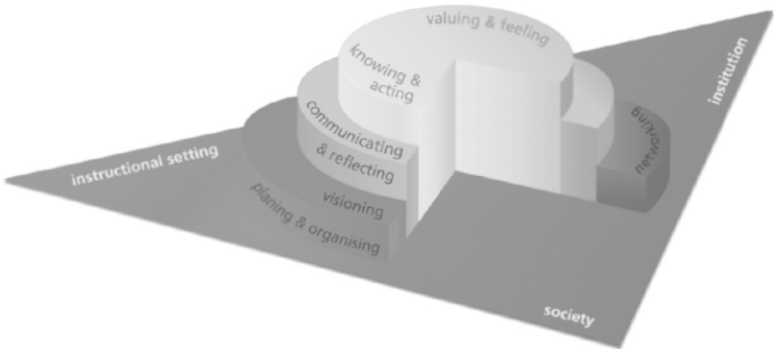

Figure 2. The KOM-BiNE model (Rauch & Steiner, 2013)

Chemistry Education for Sustainability

The original framework of ESD from the UN-Decade has been criticized in recent years for being too consensus oriented and "*thereby hiding ideological conflicts*" (Sund & Öhman, 2014). More critical alternative to ESD are called e.g. *Education for Sustainability* and *Sustainability Education* (Thomas, 2009; Birdsall, 2013). According to Albe (2013) they require "*one to consider the political dimension of* *environmental issues and their intrinsic power relationships*" (p. 185). Although acknowledging the term ESD as being the political used term in the decade of ESD, in this chapter we decided to choose the term education for sustainability. With chemistry education for sustainability, we understand corresponding education as being interdisciplinary, holistic, and values driven, promoting critical thinking, being based on multidimensional methods and involving participatory decision making (Thomas, 2009).

Like Wheeler (2000), we express hope that students through chemistry education for sustainability will develop skills and personally act on both the individual and societal level responsibly. This includes developing:

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

The role of critical media literacy

For achieving the goals of education for sustainability the objectives of science education need to be connected to other concepts. One specific set of skills mostly important for education for sustainability is *critical media literacy*, in particular the ability to critically review and deal with information presented in the mass media. Scientific literacy needs to connect critical media literacy and responsible consumership (see Chapters 10 and 11 of Belova et al. and Chang Rundgren & Rundgren in this book).

In order to act in accordance with sustainability and contributing to societal sustainability discourses, responsible citizens need competences such as the ability to examine information critically from newspaper, TV, or the Internet to make well-informed decisions about environmental, lifestyle and consumption patterns (Elmose & Roth, 2005; Jarman & McClune, 2007; Mogensen & Schnack, 2010). Such competences were thought to be facilitated by *Scientific Literacy*, which has been in focus in the area of science education in the last decades (Hofstein et al., 2011). However, the role of critical media literacy as the ability to critically examine and accordingly react to information in the media regarding science and technology related issues were not always sufficiently acknowledged in the past by all the different concepts of scientific literacy (Rundgren et al., 2012). Beside the news media, skills also have to be promoted to understand and develop a critical attitude towards science and technology related information in advertisements, product test reports, or everyday life communication (Marks, Stuckey, Belova, & Eilks, 2014). Students need to develop skills to analyse the media but, also investigate how stakeholders in society produce, distribute, and use respective pieces of information (Eilks, Nielsen, & Hofstein, 2014; see Chapter 10 of Belova et al. in this book).

Suitable topics for Education for Sustainability

Education for Sustainability is not only about instrumental training to be able to make better decisions; it is also about developing critical and educated citizens who, in making decisions, are aware of the influence of ideological, cultural, and historical contexts. Decisions in these fields require knowledge from and understanding about science in general and chemistry in particular. In the science education literature such issues are called *socio-scientific issues* (SSI) (Ratcliffe & Grace, 2003; Sadler, 2009, 2011). Also Hodson (2011) argues for an embedded approach which connects science learning to goals of critical scientific, technological, and environmental literacy, in short to *critical scientific literacy*.

Chemistry knowledge and skills for understanding and contributing debate on SSIs has also been called *chemical literacy*. It can be defined as knowledge about (a) chemical models and concepts, (b) chemical research processes, and (c) societal contexts, where chemistry is of relevance (Shwartz, Dori, & Treagust, 2013). Traditional school chemistry driven by the structure of the discipline has been dominated only by (a) and (b), whereas chemistry education focusing SSIs emphasizes them all (Eilks et al., 2013; Sjöström, 2013a; Sjöström & Talanquer, 2014). Chemical literacy in this broader meaning is about understanding "*the contribution of chemistry in various contexts*", developing higher-order thinking skills, and having "*critical but positive attitudes towards chemistry and its applications*" (Shwartz, Dori, & Treagust, 2013, p. 40).

Respective topics for critical scientific and chemical literacy are mainly related to a specific set of domains like health, environment or risk technologies; they also should be of a certain type. Sadler (2009) suggests that useful topics are of a controversial nature, they are related to values and they encourage students to make connections to their personal lives. In more detail, recently Stolz, Witteck, Marks and Eilks (2013) elaborated a set of five characteristics including provable criteria for respective issues: authenticity, relevance, an undetermined evaluation in a socio-scientific respect, the chance for open debate, and the connectedness to science and technology (Table 1).

THE IMPORTANCE OF CHEMISTRY FOR SUSTAINABILITY

There is no doubt that chemistry and the industries related to it are in the economic heart of every developed society (see Chapter 15 of Hofstein & Kesner in this book). Industry provides the basic materials necessary for every other type of business. Several quite obvious examples of industry's positive influence on Western society and its standard of living are the benefits found in modern materials, medicine, communication, transportation, and nutrition. Chemical processes also define the basis of energy supply, modern agriculture, pharmacy, and innovative technologies. However, mass media coverage of chemistry is often biased and poorly-informed. Balanced and evidence based communication is underdeveloped (Hartings & Fahy, 2011).

Table 1. Reflecting potential topics for SSI-based science education as suggested by Stolz et al. (2013) and illustrated by the example of bio-fuels

Criterion	Description and testing	Example bio-fuels
Authenticity	The topic is authentic, when it is currently being discussed by society. Test: Common media is checked for presence of the topic, e.g. newspapers, magazines, TV, advertising	Debate on the use of biodiesel, bioethanol or BTL is present in the media. Newspaper, TV and Internet report on debate whether use of biofuels should be intensified, made compulsory, or supported by special rules in taxation.
Relevance	The topic is relevant, if respective decisions will affect the current or future lives of our students. Test: Scenarios on potential decisions are tested to see which impact they will have, e.g. consumer behavior or behavioral choices.	Decisions in respect to biofuels use will have impact on sustainability of resources in the future, prices and availability of fuels, and future orientation of mobility and the agriculture industry.
Evaluation undetermined in a socio-scientific respect	The evaluation allows for different points-of-view. Test: Media is analyzed whether controversial viewpoints are represented (by interest groups, the media, politicians, scientists, etc.).	The impact of biofuels to ease climate change is still under debate as it is the case for potential impacts of more intensified agriculture for biofuels production. Different points of view are available in the political debate and in mass media.
Allows for open discussions	This topic is able to be discussed in an open forum. Test: Thought experiments test arguments to make sure that no individuals, religious or ethnic groups would feel themselves to be insulted or pushed to the fringes of society by their use.	The use of biofuels or not is openly debated in society as it can be done in the classroom. Arguments used in the debate are sufficiently impersonally that they will not harm the individual in classroom debate.
Deals with an issue based on science and technology	This topic concerns itself with a techno-scientific query. Test: Discourse in the media is analyzed. The question is raised, whether scientific facts and concepts are addressed and either explicitly or implicitly used for argumentation.	Of course, biofuels are a techno-scientific query. Development of alternative fuels from bio-resources and corresponding technologies for their use are questions of chemistry and technology and they are used in public debate.

Two considerations of chemistry in the public

There are two ways of communicating about chemistry and its applications to the public. The one side focuses on the dangers and problems chemistry has caused to the environment. Many chemical industries around the world have not always been very careful to the environment in the past. Media reports on accidents, both on large and small scale, have significantly contributed to the negative public image of industrial undertakings in chemistry and chemistry as a field of research in many countries, especially in the Western world (Hartings & Fahy, 2011). Industrial accidents and misuses of chemistry from the past are still largely influential on public opinion concerning chemistry and chemical industries (Lazlo, 2007). Still there are many current problems that are reported upon in the media. For example, problems with plastics do not solely stem from the polymer materials composing the plastics themselves. Plastic additives used in the production process are frequently found in the environment and have been shown to bioaccumulate. Bioaccumulation in animals – and human beings – can lead to a loss of fertility and it is currently suspected of triggering or causing different diseases (Vandenberg et al., 2012). As an example perfluorinated compounds (PFCs) have been shown to be very persistent and there is concern about their health effects. However, the story that it is chemistry which is applying stronger rules from year to year, is replacing harmful compounds by less dangerous alternatives, and is seeking the way to a greener practice (see Chapter 14 by Bodner in this book) are not told from this side of reports.

Anyhow, there is also the other side. In media produced by stakeholders from the chemistry sector, typically, the benefits are emphasised, and risks are sometimes being excluded. Products are often described in an uncritical way (Sjöström, 2013a). Christensson and Sjöström (2014) showed recently that thematic chemistry videos frequently do not include environmental drawbacks of the chemical applications that the videos are about. They called this *excluded environmental aspects.* On the example of the Chemistry Calender from 2011 (www.youtube.com/user/chemistrycalendar), the March video highlights the current search for new energy sources, but does not mention corresponding net emissions of carbon dioxide and its related contribution to the enhanced greenhouse effect. In the January video, modern dyes are presented; but nothing is mentioned about the drawbacks of dyes, such as heavy metals and azo dyes. In the February video, neither a general concern regarding plastics nor any drawbacks of Goretex, such as the effects of perfluorinated compounds (PFCs) to the environment, are mentioned. However, there are exceptions. In the July video the text from the Internet about that video sounded: "*Sustainable Development and chemicals? It may sound like these two don't go hand in hand but could we really live without chemicals?* […We] *learn that chemists have an important role in the work towards a sustainable future*."

Chemical production works under resources consumption and influence on the environment. It has also impacts on the economy and on society in general. Only a naïve view can imagine stopping all the chemical processes that impact these domains. Relevant chemistry education needs to develop understanding of chemistry as being an integral part of our life. Innovations in chemistry and corresponding technology will offer a chance to overcome the described dilemma and at the same time keep or increase economic and societal well-fare. Relevant chemistry education needs to educate the new generation about this ambivalent role of chemistry to find a critical and balanced position towards it. It is highly relevant that all citizens are able to understand the developments, access balanced information, and gain skills for contributing to informed decisions about them in society as part of relevant science education (Stuckey et al., 2013). That means that in the teaching of chemistry it is highly relevant that the learner understands that chemistry is both a science and a technology, a *techno-science* (Sjöström, 2007; Talanquer, 2013).

Taking the techno-scientific nature of modern chemistry into account, Aikenhead (2003) argued that societally relevant chemistry instruction must go from "*an uncritical adulation of science (scientism)*" to "*a healthy scepticism open to critically evaluating modern science and technology*" (p. 125). For doing so, chemistry can be understood having four aims: to explain, analyse, synthesize and solve technical problems (Christensson & Sjöström, 2014). All these parts have important roles in the contribution of chemistry and chemical technology to sustainability. Pure, analytical, and environmental chemistry deal with explanations and analysing the environmental impact of chemical processes. Synthetic, technical, and industrial chemistry concern with syntheses, engineering, and production. That the role of chemistry is both to explain and to find technical solutions can be exemplified with the following quote from the March video of the Chemistry Calendar: "*Chemistry plays a role in pretty much every step of the global warming process, from explaining its source to finding new improved solutions for the future.*" So there are also videos reporting potential solutions developed by chemists for major challenges on the regional and global level. In the November video, biotechnology is in the focus and it is reported that yeast cells can be used to produce alternative sorts of plastics. The video reports on biodegradable products that can be recycled or decomposed, such as cellulose-based diapers.

Sustainable and green chemistry

The video examples described above are only some of the many possible contributions to sustainability that chemistry has to offer. A general term for chemistry aiming at more sustainability in the development of our society is sustainable chemistry (Böschen, Lenoir, & Scheringer, 2003). Colucci-Gray, Perazzone, Dodman, and Camino (2013, p. 135) suggest to understand what they call *sustainability science* as, "*the ideas of complexity of natural systems and the need to operate in conditions of uncertainty and incompleteness of human knowledge have provided the foundations for the articulation of a sustainability science*." Similarly one could talk about sustainable chemistry, although this term is also used as a big initiative of the European chemical industry (www.suschem.org) aiming at similar goals but focusing more the ideas of green chemistry, as it was developed in the 1990s in the US (Anastas & Warner, 1998). Sustainable science in the understanding of Böschen et al. (2003) is a broad interdisciplinary approach that includes holistic thinking instead of reductionism, as well as transdisciplinarity and democracy- and ecojustice-driven innovations (see also Sjöström, 2007, 2013b; Zoller, 2012). In their paper, Böschen et al. (2003) argue that uncertainty and ignorance should be treated more explicitly in chemical research and as a part of relevant chemistry education. They suggest:

> Establishing a more explicit and mutual relationship between scientific work and societal needs and values requires the epistemological assumptions of chemistry as a natural science to be rethought because, traditionally, the natural sciences do not have 'interfaces' for this kind of interaction with stakeholder groups and for reconciling non-scientific, for example ethical, values and scientific objectives. (p. 94)

In green cemistry, a lot of effort is undertaken to make research in and applications of chemistry less poisonous and less hazardous (Anastas & Warner, 1998). Lozano (2013, p. 186) writes: "*Green chemistry is the response of the chemical field to evolving global needs*." It is oriented towards efficient production in chemical industries, but it is also used for reducing resources consumption and environmental as well as health impacts in laboratory work, research, and education (Sjöström, 2006; see the contribution of Bodner in this book). Thus, it is also important for relevant chemistry education to teach about this focus since without it the learner might develop a biased picture of current chemistry research and industry. Understanding this orientation of modern chemistry towards sustainability is therefore necessary for career orientation towards modern chemistry related professions and should be part of relevant chemistry education (Stuckey et al., 2013).

It is one task, among others, of relevant chemistry education to orient the potential future scientist about the current practices in chemistry and related businesses. But also the potential non-scientist future citizen needs to know that limited resources and a constantly growing consciousness of the value of environmental protection are both among the driving forces of moving towards more sustainability in modern chemistry. Green chemistry aims at making chemistry more energy efficient, at reducing waste disposal, and/or producing innovative products with less consumption of natural resources or unwanted health effects (Anastas & Warner, 1998). Alternative processes and reaction pathways are designed, new materials and products are developed contributing to meet our needs today, but also those of the future generations. These are tasks for chemists and engineers, and it were the chemists who gave themselves this framework, who worked out its guidelines, and started operating it into application. Also the increasingly strict legal restrictions for the handling of chemicals contribute to this development; and also this development is partly driven from within chemistry itself.

In 2012, Iles and Mulvihill described green chemistry as an emerging multi-stakeholder community: "*The sustainability goals that green chemistry seeks to address involve complex social, ecological, market, organizational, and scientific issues that span global production chains, multiple temporal and spatial scales, and societies*" (p. 5643). It is a complex interplay between many different stakeholders (university, government, industry, etc.), disciplines (ecotoxicology, chemistry engineering, public health, etc.), factors (chemicals management, legal restrictions, market conditions, societal values etc.), and professions. The students need to learn that without the chemists being involved and offering ways for sustainable development and how to do it, sustainability would be doomed to fail. For vocationally relevant chemistry education (Stuckey et al., 2013), to learn about this interplay will provide chances for career orientation and finding a suitable profession for the learner in chemistry related businesses. However, in the complex community connected to sustainable chemistry there are many other professions that offer good career chances. Thus, relevant chemistry education should also contribute understanding this change of emphasis in chemistry and chemical industry to the future non-scientist, since many other societal and professional groups beyond the chemists will potentially have to make decisions according to corresponding issues in question while working, e.g., in business, politics, public media, law, health or environmental focusing professions.

CHEMISTRY EDUCATION FOR SUSTAINABILITY IN PRACTICE

Vilches and Gil-Pérez (2013) stated that "*chemical education is an ethically laden activity that can and must incorporate sustainability as an essential dimension*" (p. 1869). It is the central role of industrial production based on chemical principles that gives chemistry education a central role in education for sustainability. Examples of this include the current debate concerning climate change and potential avenues of action (Feierabend & Eilks, 2010), the existence of (side-) effects caused by goods used in our personal lives (Marks & Eilks, 2010), the various alternatives for energy supply (Feierabend & Eilks, 2011), innovative products from chemistry which may aid in preserving natural resources (Burmeister & Eilks, 2012), or the interaction of chemical industry with local and regional economy and society (Hofstein & Kesner, 2006).

In all the applications of chemistry in real world issues a full understanding of the issues requires learning about how chemical developments are interwoven with ecological, economic and societal impacts and how the decisions resulting from these issues will impact life on the individual and societal level (Burmeister et al., 2012). With the suggestion of Stuckey et al. (2013) to understand the relevance of science education as having consequences, all these issues are good examples demonstrating the relevance of chemistry education since decisions and developments in all these issues will directly impact the students' life today or in future. Such consequences encompass options for political actions, potential consumer choices, or availability of resources as it was described by Stolz et al. (2013). They used the term 'relevance' in respect to justifying socio-scientific issues for *Bildung*-oriented chemistry education.

By operating socio-scientific issues from the sustainability debate, chemistry education offers great potential for bettering the level of general educational skills among students in the sense of participatory learning (Eilks et al., 2013). Using controversial issues selected carefully from chemical, industrial and technological sources allows students a chance to experience firsthand how questions related to science or technology are handled within society. By mimicking the societal mechanisms of information transfer, debate and decision-making, learners have the opportunity to develop their personal capabilities in these areas (Marks et al., 2014). This can contribute in fostering pupils' skills in all of the above mentioned domains and thus help chemistry education to achieve a broader range of goals (Marks & Eilks, 2009; Sadler, 2009; Sjöström, 2013a), while in the meantime to contribute the relevance of chemistry education through general educational skills development as suggested by Stuckey et al. (2013).

In 2012, Burmeister et al. suggested four basic models for how to connect sustainability with chemistry education:

- Model 1: Adopting green chemistry principles to the practice of practical work in chemistry education
- Model 2: Using sustainability contexts to promote content learning as a base for understanding the chemistry behind sustainability issues
- Model 3: Teaching about controversial sustainability issues by socio-scientific issue (SSI)-driven chemistry education
- Model 4: Making education for sustainability a driver of school (program) development

Burmeister et al. (2012) suggest that from a domain-specific curricular point of view it is especially the model 3 that has potential for education for sustainability when it comes to formal chemistry education classes.

Sustainability issues in SSI-based chemistry education

SSI-driven chemistry teaching on issues of sustainability does not primarily focus the learning of chemistry as a subject or the chemical basics behind sustainability issues per se. The focus is on learning how developments in chemistry can be and actually are evaluated and discussed within society using all of the sustainability dimensions (Burmeister et al., 2012). Corresponding approaches not only constitute the explicit learning *of* chemistry and technology, but also include the learning *about* chemistry and its applications as they are dealt with in society (Sjöström, 2013a). Examples with respect to sustainable chemistry include the ongoing controversy about the use of biofuels (e.g. Eilks, 2002; Feierabend & Eilks, 2011), the application of specific compounds and alternatives to them in everyday products (Marks & Eilks, 2010), or the evaluation of innovative products from chemistry using a multidimensional approach (Burmeister & Eilks, 2012). Pedagogies for understanding societal debates and developing appropriate skills to actively participate in them are systematically built into the lesson. Students learn how to take part in societal decision-making in order to contribute to shaping a sustainable future.

In 2009, Marks and Eilks described principles of socio-critical and *Bildung*-oriented chemistry teaching. They suggested a problem-oriented approach and argued that context-based chemical education should go beyond taking applications and daily-life only as a context to frame subject matter learning: "*STS-oriented chemistry lessons [should] include reflective overview of chemistry, its industrial* *applications and its ecological and socioeconomic impacts*" (p. 233). They reported that daily life contexts do not automatically generate motivation among the students: "*it seems that chemistry topics must include more than contexts (even if they stem from everyday-life) in order to motivate student science learning and stimulate pupils' interest and critical skill building*" (p. 240). Their suggestion, as also given by Sadler (2004), is that lesson plans that start with current, authentic and controversial problems being debated in the public are more challenging. Examples for such an approach are everywhere and include issues concerning biofuels, different diets, or synthetic musk fragrances in shower gels (Marks & Eilks, 2009). Other possible cases are e.g. additives in consumer products, alternative plastics, doping in sports, tattooing, or nano-technology (Burmeister & Eilks, 2012; Jones, Blonder, Gardner, Albe, Falyo, & Chevrier, 2013; Ratcliffe & Grace, 2003; Stolz et al., 2013, Stuckey & Eilks, 2014). It is also possible to work with historical cases as for example Midgley's inventions tetraethyl lead as an antiknock gasoline additive and chlorofluorocarbons (CFCs) in refrigerators (Viana & Porto, 2013). However, Stolz et al. (2013) recently suggested the importance of actual authenticity, current relevance, and openness in debate in society as factors for challenging debate among students (Table 1). Thus historical cases that were finally decided, e.g. by banning certain chemicals or goods, can only serve as a case for analysis, but not for challenging own evaluations and decisions.

Recently, Sjöström and Stenborg (2014) described and problematized teaching and learning about risk-related chemicals, such as additives, pollution and diverse environmental chemicals. *Chemicals Education*, as Sjöström and Stenborg call it, highlights the interplay of science, technology and society and emphasizes that the knowledge required to make decisions related to risk-related chemicals is not only scientific, but also e.g. ethical (see further below). From a chemistry content perspective *Chemicals Education* aims at understanding the nature of chemicals, natural vs. synthetic substances, doses etc. Such concepts are central in chemistry education for sustainability. According to Sjöström and Stenborg (2014) *Chemicals Education* should be based on the following three pillars: (1) the nature of chemical risks, (2) the interplay between actors in "the chemical society", and (3) pluralism and awareness regarding different "chemical discourses".

Bioethanol as an alternative fuel

In 2011, Feierabend and Eilks suggested a chemistry lesson plan on bioethanol usage from chemical and societal perspectives. They described learning following a five step strategy based upon a curriculum model by Marks and Eilks (2009) and originally developed along a lesson plan on biodiesel usage (Eilks, 2002). Lessons according the model start with actual media from everyday live to demonstrate the authenticity and relevance of the topic (Figure 3). Covers and a report from a political magazine were used to introduce the topic. The growing concurrency of food and fuel production is reported leading to increasing prices for corn in various countries. The media are analyzed to provoke questions on the topic. Questions generally cover both issues of the chemistry and technology behind the making of bioethanol, as well as about potential ecological, economic and societal impacts of biofuel technologies. According to the curriculum model represented in Figure 1, the students started learning about the chemical principles behind bioethanol technology including practical work.

Concept of the socio-critical and problem-oriented approach to chemistry teaching

Objectives	Criteria for selecting issues and apporaches	Methods	Structure of the lesson plans
Allgemeinbildung/ education through science	Authenticity	Authentic media	1. Textual approach and problem analysis
(Multidimensional) Scientific Literacy	Relevance	Student oriented chemistry learning and lab-work	2. Clarifying the chemistry background in a lab environment
Promotion of evaluation skills	Evaluation undetermined in a socio-scientific respect	Learner centred instruction and cooperative learning	3. Resuming the socio-scientific dimension
Promotion of communication skills	Allows for open discussion	Methods structuring controversial debating	4. Discussing and evaluating different points of view
Learning science	Deals with questions from chemistry and technology	Methods provoking the explication of individual opinions	5. Meta-reflection

Figure 3. Framework outlining the socio-critical and problem-oriented approach to chemistry teaching (Marks & Eilks, 2009)

Learning the chemistry behind the bioethanol technology allows the students to understand about the sources and processes needed to apply biofuels on a large scale. It allows an evaluation of the technology from a chemical point of view, e.g. whether there is potential to save resources or help limiting anthropogenic climate change. However, it does not allow any understanding how society is deciding about corresponding applications. Therefore the model and the lesson plan suggest a thorough analysis of which of the initial questions can be answered by chemistry and which cannot. The issues science cannot answer are political and ethical questions. In a democratic society such questions are negotiated and decided in public forums, like parliaments. Consequently, the lesson plan leads over into a role play mimicking the authentic societal practice of hearings in parliaments' committees. The students make themselves familiar with different roles, like fuel producers, car industry, environmental protection groups, etc. A formal hearing is made, the group representing the parliaments' committee has to suggest a decision and has to justify it against the different stakeholders. Finally, a meta-reflection is made to which extend arguments from chemistry and technology are crucial in corresponding decisions and how they have to be balanced with arguments from, e.g., ethics, economy, or ecology. For details see Feierabend and Eilks (2011).

Conventional plastics and bioplastics

Starting from the same curriculum model (Figure 3), Burmeister and Eilks (2012) suggested a lesson plan on plastics. They connected the learning about conventional and alternative plastics with the problem of growing amounts of plastic waste all over the world and in the oceans. Also this lesson plan started with authentic media from newspapers and brochures from industry. A phase of learning about polymers, their structure and properties, different sorts of plastics, and their fields of application set the base for evaluating the different alternatives later. It became clear again that chemistry allows students to understand and evaluate the alternative plastics from a technical point of view. However, it does not allow for a broad evaluation to whether bioplastics have potential for contributing significantly to sustainability.

For learning how materials and goods are evaluated in society under a broader focus a new pedagogy was developed. The students had to mimic the work of a professional product testing agency. Mimicking the work of the *Stiftung Warentest*, a public body providing product tests in all areas of consumer goods, was operated to allow for how evaluations under consideration of the different sustainability dimensions. The method focuses on the points where negotiation and evaluation processes necessarily occur during testing procedures. By applying sustainability-related criteria for evaluation purposes, this method reveals the competitive nature of the various sustainability dimensions, including the need to balance them fairly in order to arrive at an equitable and holistic evaluation for a given product.

Three plastics were to be evaluated in comparison: polyvinyl chloride (PVC), polyethylene terephthalate (PET) and thermoplastic starch (TPS). These three plastics were chosen because of their significant (dis)advantages, which largely contradict one another. PVC is cheap and broadly applicable. However, PVC remains quite controversial. Even though modern, high-quality PVC is hardly more problematic than other types of plastics and recycling is safe, this fact is hardly ever heard in public discourse. Disadvantages of PVC, including risks arising from unplanned combustion and improper disposal, dominate the public perception. In contrast, the reputation TPS remains largely untarnished. It is a “bioplastic” and is bio-degradable and made (at least partially) from renewable resources. However, the uses are still few and its price is relatively high. TPS may contribute conserving crude oil resources, but large-scale production might also increase the risk of overly intensive agricultural land use. In the same vein, the public hardly ever hears about the negative side of PET, which is well-known for its use in drinking bottles. PET is largely considered as a benign substance, even though recycling PET products successfully is a highly volatile societal problem. Until recently, old bottles were seldom recycled in Western countries. Instead, they were shipped off to developing countries or to China, where they were disposed of or remanufactured into fleece pullovers and other items under deplorable environmental and social conditions. Also the ‘carbon footprint’ of the transport is an often neglected factor. With modern innovations in technology, however, PET can now be recycled under economically sound conditions in Western countries. But this technology is unfortunately not broadly applied in many countries.

The product testing in class begins by identifying and negotiating the individual evaluation dimensions. The utility of plastics, which has been discussed in previous lessons, generally becomes a logical dimension in the evaluation. Availability and price are also easily derivable criteria. Environmental friendliness, decomposability and recycling suitability become additional touchstones, thanks to introduction of the problem of plastic waste in the beginning lessons. In order to lend more structure to the overall discussion, the pupils are introduced to a basic model of sustainability, driven by the interconnectedness and balancing the ecological, economic and societal impacts of a given product. It is important to recognize that pragmatic criteria (a product's properties and utility) are combined with more economic and value-driven dimensions from the sustainability debate, namely economic (salability, cost-price-effectiveness, availability), ecological (environmental effects, health in production, disposal/recycling) and societal (production, recycling under appropriate social standards) impacts.

During the actual process of product evaluation, the students must first negotiate weighting the factors attributed to the various dimensions. This step is introduced on a respective worksheet (Figure 4). The students are free to suggest each their own weighing based on their values, feelings, and preferences. The suggestions always cover an extremely wide spectrum. Some participants find environmental friendliness to be the most important factor; others view technical properties as more important. Ways of negotiation or decision for taking the mean have to be drawn. Each student is then assigned the task of individually rating one of the three plastics. Symbols ranging from "++" to "-" were used, which parallel German school grades of 1-5 (Figure 4), analogous to A, B, C, D, and F in many English-speaking countries. Specially-designed texts were employed, in which information about each of the plastics was tailored to the various criteria. Pupils carry out the evaluation individually. Then they negotiate the values for their particular sort of plastic for each category. New learning groups are composed of at least one expert per plastic type. The learners discuss their various decisions with one another, including their reasons for positively or negatively evaluating a product. It quickly becomes clear while summarizing the evaluations that any advantages in one domain are often negated by disadvantages in other areas.

The sequence is ended with a meta-reflection discussing both the end decisions and the lessons which can be learned from the process. This reflection decisively focuses on both where and to what effect individual decisions affect the end result. The goal of this exercise is to make the pupils think about the decisions made during the process of product evaluation. The processes of evaluation can therefore easily lead to two equal overall values, despite different constellations in the chosen weighting factors. It is clear that the end focus needs to be the question of how objective and balanced evaluations reported to the public frequently are. This includes the question of which role scientific evidence or sustainability criteria actually play in reaching such important decisions. For details see Burmeister and Eilks (2012).

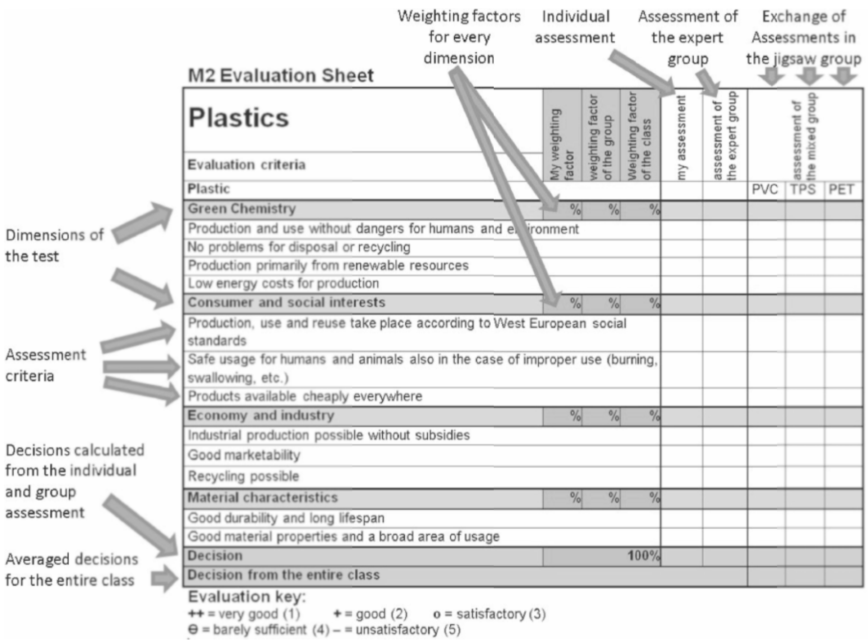

Figure 4. Part of the working materials for the product testing method using the comparison of various plastics as an example (Burmeister & Eilks, 2012)

Life-cycle analysis in chemistry teaching

Juntunen and Aksela (2013) suggested a similar framework by learning about formal procedures of life-cycle analysis in chemistry classes. They claimed that "*sustainability education in chemistry teaching through combining a socio-scientific issue, life-cycle analysis (LCA), with inquiry-based learning (IBL).*" During an in-service training course chemistry teachers got the task to develop a lesson plan on LCA. As a basis guest lectures were given about e.g. the *chemicalisation* of the environment and green chemistry. In small groups teachers discussed techniques of LCA of consumer products and methods for inquiry learning by LCA. The approach involved project work, a theme for the chemistry lesson or an environmental chemistry course. Examples of life-cycle topics were water, paper, cotton, plastic bottles and electronics. Examples of working methods were debate in teams, role play, field trip, collaborative design of new product, video and laboratory work. For details see Juntunen and Aksela (2013).

CONCLUSION

An even more thorough model (Model 4, see page 174) was suggested by Burmeister et al. (2012) to exist for integrating chemistry teaching and education for sustainability, namely making sustainability as the driver for the development of the whole school program. In this case, sustainability education is operated as the driver of the development of a whole institution (Rauch, 2002). Such an approach demands opening chemistry classrooms even further as compared to using SSIs in the teaching (Breiting, Mayer, & Mogensen, 2005). The model suggests that whole school life and teaching should become part of sustainability education (Thomas, 2009). Consequences are the opening of the institution towards external partners, cross- and interdisciplinary teaching, and operating learning into concrete actions (Rauch & Pfaffenwimmer, 2014). This might form the most thorough approach to education for sustainability. However, as Burmeister et al. (2012) also stated, this approach often is difficult to operate. It asks for educational policy allowing such a change, a whole school being open and skillful to operate corresponding change, and there is a risk that more traditional educational objectives, like career orientation in traditional subjects or preparation for more conventional academic education, which also form part of relevant chemistry education (Stuckey et al., 2013), might be pushed towards the fringes of science education.

The discussion in this chapter shows that there are good opportunities for connecting chemistry and education for sustainability for more relevant chemistry education as suggested by Stuckey et al. (2013). Taking up issues and questions from the sustainability debate in a SSI-based curriculum approach allows for challenging the students and contribute to general individual and societal-focused educational skill development. This combination contributes to individual relevance by orientation about the development of the individual environment and skill development how to behave and react to it. It promotes societal relevance of chemistry education by allowing the students to learn how society is focusing sustainability and how one can contribute to corresponding societal discussions and decisions. There is also contribution to vocational relevance since the students can learn about and get prepared for the many chemistry-related professions connected to sustainable development and about other professions beyond chemistry related to sustainability issues which are indirectly linked to the chemistry aspects thereof.

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10. THE IDEA OF FILTERED INFORMATION AND THE LEARNING ABOUT THE USE OF CHEMISTRY-RELATED INFORMATION IN THE PUBLIC

This chapter discusses the idea of filtered information. The existence of filtered information suggests that most science-related information used in the public is not scientific in the strictest sense of the word. Such information is mainly presented to the public by non-scientists in the forms of news media, brochures, advertising, or personal communication. These individuals tend to be journalists, politicians, advertising experts, or people from various professions and stakeholder groups. Such groups employ information derived from science, but they transform it in various forms on its way to the public. Chemistry education should provide sufficient subject matter knowledge and critical skills so that pupils can evaluate the chemistry-related information used in public discourse and in the media. This skill set is necessary for understanding how science-related information reaches the public and how it is used by different shareholders to influence individuals and public opinion. It is also needed to cope with general public discourse and to deal with the media and their offerings in a critical fashion. This chapter discusses a socio-philosophical framework for understanding the science-to-society relationship of different science-related information types. It presents organizing principles for modeling the information flow from authentic science to the public sphere. Different pedagogies are also suggested and illustrated by classroom cases for learning about how chemistry-related information is used in non-scientific societal practices.

INTRODUCTION

Critical scientific media literacy has been suggested as an essential component of scientific literacy (Chang Rundgren & Rundgren, 2014), since the mass media and advertising have a large impact on young peoples' lifestyles, behavior and beliefs (Byrd-Bredbenner, 2002; Dhingra, 2003; Villani, 2001; Vereecken, Todd, Roberts, Mulvihill, & Maes, 2006). This makes learning about how chemistry is dealt with in the media an essential component of relevant chemistry education (Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013). It also allows chemistry education to more thoroughly contribute to general educational skills development (Sjöström, 2013).

I. Eilks & A. Hofstein (Eds.), Relevant Chemistry Education – From theory to practice, 185–203.

Students need to gain skills to critically analyze and react to science-related information presented in the news media and other sources (Chang Rundgren & Rundgren, 2014; McClune & Jarman, 2012). This demands an understanding of the subject matter behind any chemistry-related information in the media. It also calls for the development of skills in understanding exactly how chemistry-related information enters the media and how such information is used to influence public opinion in issues related to science and technology (Eilks, Nielsen, & Hofstein, 2013).

This chapter presents a socio-philosophical framework based on the works of the famous Polish philosopher and bacteriologist Ludwik Fleck (Fleck, 1935/1980). This framework allows an understanding of relationship between science and society when it comes to delivering science-related information to the public and suggesting its possible uses (Stuckey, Heering, Mamlok-Naaman, Hofstein, & Eilks, 2015). Based on Fleck and his ideas, different organizing principles are presented as aids for understanding the information flow from authentic science to the public (Eilks et al., 2013). A discussion of Fleck leads to the idea of filtered information as a concept which helps us to understand the transfer of information from authentic science sources to the general public as suggested by Bauer (2009). Different pedagogies for learning about how chemistry-related information is used in non-scientific societal practices are also presented.

THE IDEA OF FILTERED INFORMATION

When considering society's use of chemistry-related information one has to be aware that the majority of our students in compulsory secondary science classes will never pursue careers that are science-related (Hofstein, Eilks, & Bybee, 2011). Thus, only a minority of our students from secondary schools will ever come into contact with authentic science, real scientists, and real chemistry research.

Truly authentic science or chemistry research can only be found in the respective research institutes, scientific publications, or corresponding conferences. Access to such environments or knowledge is mainly limited to scientists. Several reasons for this limitation are that only certain persons have access to research institutes, scientific literature, and congresses and that organizational reasons and/or the question of comprehensibility sometimes limit access. Only sufficiently educated scientists are able to read the texts in scientific publications with their formal scientific language, technical terms, and symbols. Moreover, access to authentic scientific communications even among scientists is mainly restricted to their own domain of expertise.

For this reason, most of the science-related information with which the vast majority of our students will come into contact does not stem directly from the domains of science in general or chemistry in particular. Beginning with academic handbooks and textbook literature, the reader is no longer dealing with the core of original scientific research (Bauer, 2009). The question also arises whether readers are still dealing with original scientific information in the context of popular science magazines or school textbooks. In almost all everyday media offerings and in most public discussions there is no direct contact to real science, scientists and authentic scientific information. We need to be aware that the science-related information used in public is in most cases not even prepared or presented by a scientist who is an expert in the particular area in question (Marks, Stuckey, Belova, & Eilks, 2014).

The science-to-society relationship in a model based on Ludwik Fleck

In everyday life, the public media, and the context of societal debate, there are rarely provisions made to present authentic scientific information. As early as the early 20th century, the famous Polish physician, biologist and philosopher Ludwik Fleck (1935/1980; 1979) clearly outlined the argument that different forms of scientific information exist between authentic science sources and the public arena (Bauer, 2009; Stuckey et al., 2015).

Stemming from Fleck's theory (Fleck, 1935/1980; 1979) science can be understood as consisting of concentric spheres containing different kinds of information. In this model, a marked-off field of authentic science activity, called the "esoteric core" of science, is surrounded by several concentric circles. Authentic scientific endeavor takes place in the esoteric core and is mirrored in the resulting articles in scientific journals and at conferences. At this level the information is still under debate and scientists are searching for recognition within the collective of other scientists. If the information has been accepted by the collective of scientists, which Kuhn termed the "scientific community" (Stuckey et al., 2015), it will eventually find its way into academic handbooks and textbooks. During this transfer, initial steps of information selection and simplification take place. This is done in order to condense the entire corpus of knowledge into concise overviews and make the information accessible for the target audience, which may consist of other researchers or students. Fleck calls this domain of knowledge "handbook science". Beyond handbook science there are further domains, including the domain of the public understanding of science for the 'educated amateur'. Publications like *Scientific American* belong to this domain of information, which Fleck still considers to be part of science. However, there are other types of media containing scientific information like newspapers, TV, and advertising. These media are beyond science, but nevertheless they do contain science-related discussions. Every step away from the science core entails further steps of selection, simplification and interpretation of the scientific information (Figure 1).

Bauer (2009) describes gradients of simplification, iconicity, concreteness, certainty of judgment, and controversial reception whenever information is transferred from one of the domains to another. This gradient is clearly driven by the purpose and the target audience for which the information is prepared. He argues further that nearly all non-academic domains in society and education only possess a minimal overlap with the field of the public understanding of science.

They also have hardly any overlap with the domains of authentic science itself and the corresponding academic literature.

The model shown in Figure 1 explains why science-related information used by the public is accessible only after several steps of transformation. Information in public usage is presented to the average citizen mainly through special interest groups, politicians, journalists, or advertisers. At this stage, the information is no longer authentically scientific, no matter whether the source is TV, radio, newspaper, brochure, or advertisement. Every citizen is confronted with this kind of transformed information, which can better be called "filtered information" as was suggested by Hofstein et al. (2011).

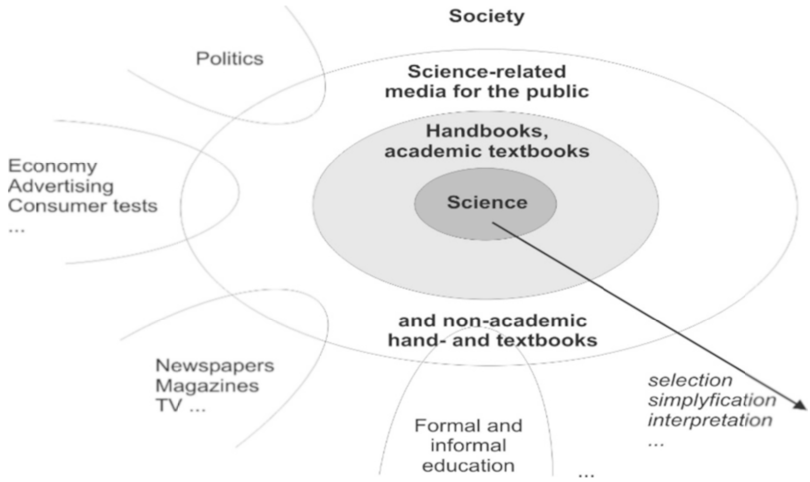

Figure 1. The science-society-relationship with regard to the types of information sources (based on Bauer, 2009)

In other words, the path which information for understanding socio-scientific issues takes in order to reach non-scientists is very long and indirect. The original information is processed and filtered from one domain to another through many single steps. This process also occurs within the domains themselves. This is performed by individuals or groups, through whom the processes of selecting, simplifying, and interpreting information in each of these steps is carried out.

Educational models based on the philosophy of Ludwik Fleck

Another model may allow to also understand the processes of information transformation and transfer. The indirect link of science to society concerning information flow can also be understood with the aid of models of information transfer. Belkin (1984) describes information transfer as a dynamic interaction between three components: the user, the knowledge resource, and the intermediary mechanism. In Belkin's model the user initiates the information transfer due to a problem, goal, or intention. The intermediary mechanism mediates between the user's intention and interest and the original source of knowledge. In the current case under consideration, the intermediary mechanisms are extremely complex. Each step of information transfer from science to the general citizen is carried out by individual persons or collectives of people, for example scientific journalists, news agents, authors, editors. As a result, the final product is substantially different from the original, whether for reasons of comprehensibility or due to intended purpose of information usage.

The information which is finally presented to the end-user is filtered by the individual foreknowledge, interests, and linguistic competencies of the writer and by these same factors in every other person involved along the information transfer chain. The further we move towards everyday life situations and the general public, the higher the chance that information most probably has been filtered. Greater distances from the domain of authentic science mean an increased likelihood that the people involved in-between do not possess the comprehensive, expert subject matter knowledge necessary for securing reliability during the information transfer.

In conclusion, the interaction of science-related information with everyday settings requires not only simple evaluation of the pertinent scientific facts, but also comprehension of the path taken. Frequently, *which* pathway the transmission of information has followed and exactly *which* interests and biases have played a role in its transfer are more important than the raw information itself.

This points towards the fact that many different constituents play a part in the overall process. It goes without saying that such groups as lobbyists, special interest groups, advertisers, and politicians have their own agendas and biases. Yet journalists also possess certain interests, even if they are as obvious as the wish to provide the readers with an attractive journalistic product. It has already been mentioned above that the subject matter qualifications of the author are most often not clearly recognizable and/or confirmable. But the filtering process is by no means determined solely by the knowledge-based scientific competency of the author. Of equal importance are such factors as personal interest and an ability to clearly present and deliver information in a solid, understandable, and target-oriented manner (or at the least to intentionally and self-consciously craft such representations in an unbiased fashion which mirrors reality as accurate as possible).

In this regard, we would suggest a model using a double-filter mechanism for better understanding and teaching about information transfer from science to society (Figure 2). Understanding the double-filter is directly related to a comprehension of how to (re)act towards such information. This is true, for example, in the case of determining the credibility of an information source. This includes employing various strategies such as self-consciously contrasting different pieces of information which stem from sources with diametrically opposed interests.

Preparing the younger generation for participation in societal debates on and decisions about techno-scientific questions is part of relevant chemistry education (Stuckey et al., 2013). This goal should enable every citizen to participate in public decisions with respect to both performing science and dealing with the societal and environmental impacts of science and technology. Ludwik Fleck's theory (1935/1980) also moves in this direction.

Figure 2. The double-filtering process of scientific information transfer (Eilks et al., 2014)

Decisions in domains beyond the esoteric core and the concentric circles of science, e.g. politics, ethics, and economics, have a huge impact on scientific research and work. One example is the fact that governments set ethical guidelines for research and make financial decisions determining which projects to fund (or not). Whether as individuals or in groups, societal players transfer and transform public opinion and societal interest into a framework in which scientists must work. Once again, journalists, interest groups, and politicians play a major role in this area. Figure 3 shows how this reverse society-to-science link might be illustrated for students.

Figure 3. The indirect influence of the public on science to society via specific societal stakeholders (Stuckey et al., 2015)

MIMICKING AUTHENTIC SOCIETAL PRACTICES IN ORDER TO LEARN ABOUT SCIENCE-RELATED INFORMATION USE IN THE PUBLIC SPHERE

Studies on science teachers' media use in teaching have disclosed that educators tend to use media in very limited ways. Critical media literacy issues as seen from a socio-scientific perspective are rarely addressed (Jarman & McClune, 2002; Kachan, Guilbert, & Bisanz, 2006). The model of double-filtered information might serve as a framework to make the teaching of hot-button media issues easier for teachers.

Classroom learning through models addressing the link between science and society can be based on Ludwik Fleck's ideas. This can be performed by mimicking authentic societal practices, which clearly show how science-related information transfer and decision-making in society are connected (Eilks et al., 2013). Learners can imitate the work of individuals or professional groups (in this case: non-scientists). Namely, they can personally select and employ science-related information in order to influence a socio-scientific controversy in which they themselves take an active part.

Suitable activities for such teaching efforts include: 1) using role-playing exercises to highlight public debate and decision-making committee work (Marks, Bertram, & Eilks, 2008), 2) employing a business game to see how politicians use scientific expertise for their decisions (Feierabend & Eilks, 2011), 3) selecting teaching methods which make learners work like a journalist (Marks, Otten, & Eilks 2010), 4) choosing editorial feedback to letters to the editor in youth magazines as an aid to promoting discussion (Stuckey & Eilks, 2014), 5) performing and reporting product tests just as a consumer test agency would (Burmeister & Eilks, 2012, see Chapter 9 by Sjöström et al. in this book), and 6) personally analyzing and creating advertisements (Belova & Eilks, 2014a). Such activities encompass the four goals of media literacy education, namely accessing, analyzing, evaluating, and creating media (Hobbs, 2003). They also help to achieve such activities as viewed from the science perspective.

Mimicking public discussions

A lesson plan based on fats and carbohydrates was designed and carried out by Marks et al. in 2008. This teaching unit was introduced through the debate over low-fat and low-carb diets which was highly visible in print media and TV talk shows at that time, and which is still under debate. The introduction to the lesson plan uses various advertisements of different sorts of potato chips as a catalyst. "Light chips" are commonly advertised with slogans claiming that the product contains 30% less fat. This serves as a springboard to catapult learners into laboratory investigations of the different sorts of potato chips.

However, such advertisements do not mean that 30% less fat necessarily equals 30% less calories. Students quickly realize that advertisers refer to "30% less fat" on purpose, rather than making the claim the chips contain "10% less calories." Yet both claims are equally valid. The widespread use of scientific claims in advertisements for different types of potato chips and various diet options serves to provoke student reflection on the use and manipulation of information by different groups in society.

The socio-critical, problem-oriented approach to science teaching suggested by Marks and Eilks (2009; see Chapter 9 by Sjöström et al. in this book) mirrors the situation quite well. This method allows students to reflect upon just how far experimental learning about potato crisps can inform them. It also gives them the theoretical background on fats and carbohydrates and allows them to better answer the question of which diets may be healthier. It also directly addresses how public opinion is influenced and formed for such topics. To support learning about the latter aspect, a role-playing exercise in the form of a TV talk show was embedded into the lesson plan (Figure 4). Nutrition experts, potato chip producers, the authors of diet cookbooks, and normal citizens are all forced to immerse themselves in their personal roles and to intensely discuss the topic. In a meta-reflection phase the students analyze the various arguments made. They discuss whether the role-players actually used chemistry-related information, whether they used it correctly, whether information was excluded or even purposely misinterpreted in order to promote the personal interests of the fictional characters. Similar cases and examples also exist for the use of biodiesel as a fuel (Eilks, 2002), or the issue of doping in sports (Stolz, Witteck, Marks, & Eilks, 2013).

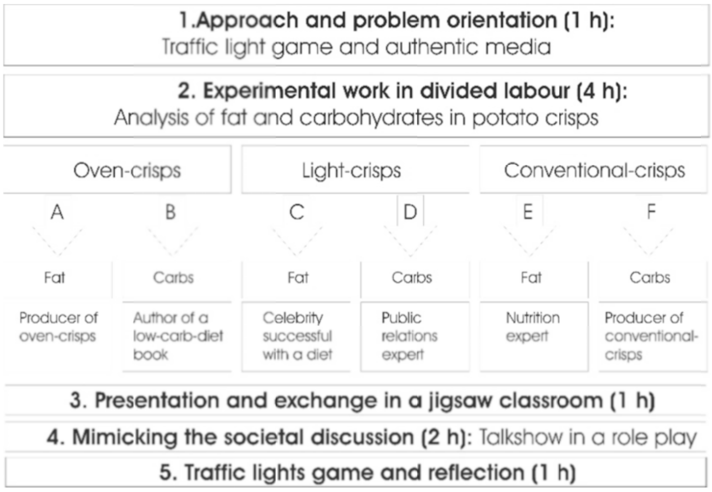

Figure 4. Overview on the lesson plan (h = one lesson period of 45 minutes)

TV talk show participants are not forced to come to any final agreement or decision. This is in direct contrast to decision-making bodies such as parliaments or parliamentary subcommittees. In 2011, Feierabend and Eilks designed a corresponding teaching unit addressing bioethanol. After learning about alcohols and their potential use as bioethanol fuel, the learners conducted a role-playing exercise centering around a parliamentary committee hearing (Figure 5). One group of students made up the parliamentary committee. The other groups acted as different shareholder groups. The students also learned that such official hearings follow specific rules. Each group presented their arguments to the committee as expert groups would receive the same amount of time. The committee was then required to deliberate and to suggest a final, rational decision. After the activity, the students were also asked to reflect upon which of the arguments selected had been the most convincing and why. This was not always a question of the arguments themselves, but also how convincing they were presented. A related example of a business game concerning climate change is described in Feierabend and Eilks (2010).

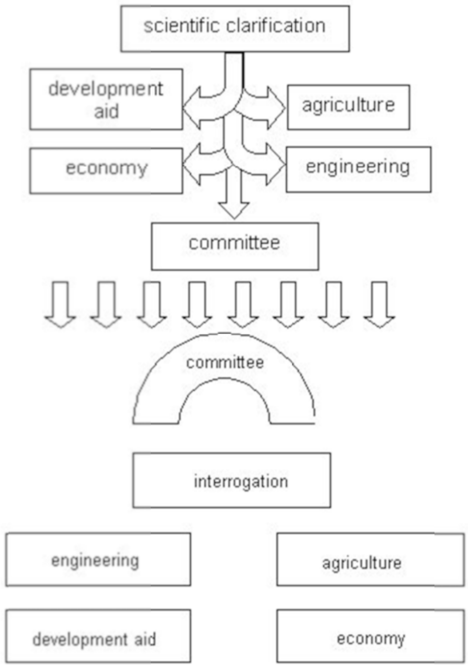

Figure 5. Structure of the panel of an experts' business game

Working like a journalist

In everyday life, it remains a rarity that so-called "expert" journalists have ever received explicit education or training as science or technology reporters. It is much more often the case that columnists write in areas of personal interest or are assigned their tasks by their superiors by default. Such experts can normally be found in editorial positions at the larger newspapers or in media institutions. However, trained scientists are rarely an active part of the daily news team with regard to normal press offerings from radio or TV. This results in frequent mistakes or even outright falsehoods as a recurring problem in the daily press, TV programs and radio broadcasts, whether such things are intentional or not.

The journalists' personal foreknowledge in a topic area is often quite limited to what they learned in school. Therefore, they must acquire additional information from other sources. On the one hand, this can happen through personal search for topics "on their own doorstep". But if problems have an extra-local character, acquisition becomes more difficult. In such cases, a reporter facing limited time and resources is totally dependent upon outside information sources like telephone calls to experts, Internet research, and wire service communiques from press agencies. The latter provide broadcasters with selected and often sanitized information fitting the provider's own biases and perceptions. Just like an Internet search using different keywords will result in various sources, the basic information a journalist can access changes depending on which focus a particular story is supposed to have. One classroom example on musk fragrances in shower gels has already been published which shows such biases (Marks & Eilks, 2010). If the main news report focuses on jobs in the cosmetics industry, then production quotas and production locations will be added to general info about musk-based fragrances. If the threatened status of musk deer and its habitat are the focus, other information will be obtained and presented, just as other sources would be consulted if the effects of synthetic musk fragrances on wildlife in the sea were to be the topic of interest.

The journalist writes an article or prepares a news spot on the basis of such information filtering. The demands for such a piece of writing differ greatly from those for a scientific paper. The news-based report's goal is to motivate the audience to pay attention, as well as to "sell" information or a slant the message in a particular direction (i.e. manipulate the audience). To this end, one crucial piece of information or another is left out, because it may appear to be either too specific or uninteresting, or because it may even be contradictory to the goal of the news item. In order to be successful in today's marketplace, the journalist often has to produce simple, intelligible, and short messages. It is not infrequent that TV or radio producers have only a few seconds of time in which to present finished spots in the chosen format.

In 2010, Marks and Eilks presented a lesson plan employing shower gels in order to approach the problematic nature of synthetic musk fragrances in chemistry lessons. The lesson begins with pupils testing various shower gels. They compare frequently-encountered supermarket and discount products, brand names, and items with no artificial colors and preservatives. Learners are then asked for the criteria which they had used to decide on a particular shower gel. Normally the primary factor tends to be a product's smell, but brand name image and overall price are also driving factors. These criteria are then compared with the criteria suggested by a leading consumer testing magazine. The information is analyzed, which reveals the important classes of shower gel ingredients: cleaning agents, fragrances, coloring agents, skin- and hair-care substances, and preservatives. A lab-work session is used to add in-depth, scientific clarification of exactly which ingredients are found in specific products and which functions these compounds possess. It turns out that certain ingredients emerge as especially important for getting good test ratings, e.g. the avoidance of certain musk fragrances.

A short film about the fragrance industry and the importance of natural and synthetic musks introduces students to questions about the actual value of using synthetic musk fragrances. The participants are then asked to reflect upon how the media report on this issue by mimicking the work of journalists.

Groups of students act as editorial units and create news blurbs for an evening TV news show. In addition to their previously-learned knowledge on the topic, pupils are provided with information from a news ticker, much like as a news agency would release. These news ticker offerings combine many different messages about a topic from various sources (Figure 6).

news ticker Group A

Imagine that you are journalists at RTL News and receive the following messages in the editorial department! Use them to make a news report approximately 60 seconds long!

News messages:

Source: www.greenpeace.at Greenpeace Austria
11.11.5 4:03
… Humans can assimilate musk fragrances through the foods they eat. Musks are especially prevalent in fatty fishes. Human breast milk can also contain musk fragrances….

Source: www.greenpeace.at Greenpeace Austria
11.11.05 2:28
…Consumers have no way of confirming whether artificial musks are in a product or not. It is not mandatory for producers to provide a legally-binding declaration of exactly what is in their products.

Source: www.verbraucherschutz.de consumer protection agency Germany
Datum: 28.02.06
….Musk compounds exist in almost every product, whether we are talking about soaps, perfumes, or other detergents which spray fragrances into the air. Most consumers these days are not willing to abstain from the use of certain scents. Oftentimes, they do not even realize which dangers are involved and, even then, accept them as par for the course…

Source: www.verbraucherschutz.de consumer protection agency Germany
Datum: 02.03.06
..Breast milk samples were tested for musk compounds, because such substances are detectable due to their persistence (high chemical stability) even after long periods of time. These substances are stored in the food chain and therefore end up in the human body. Musk compounds were detected in the tested samples…

Source: die Umweltberatung (Environmental Consulting)
Datum: 07.03.06 7:12
..These substances are suspected of causing cancer and damaging DNA or the central nervous system. Certain compounds can also lead to allergic reactions or skin damage under the influence of light-induced reactions. Up until now only three of these substances have been forbidden for cosmetics: nitromusk ambrette, nitromusk moskene, and nitromusk tibetene…
..The number of people suffering from an oversensitivity to many chemicals is constantly growing. The unlisted, artificial musk compounds present in various products represent a problem for this segment of society…

Source: Bayerischer Rundfunk (Bavarian media)
11.11.05 00:12
…It is already known that musk fragrances in cosmetic products can cause health problems. These substances are also widespread in shower gels. Only a few of the musks have been forbidden up to the present, while maximum concentrations or time limits have been placed on others until research can clarify the issue…

Figure 6. One of the news tickers

Each group receives one of four separate news tickers, which reflect the following perspectives:

- Consumer protection agency (concerns about human contact with possible hormone-activating or carcinogenic substances and allergens),
- Cosmetics industry (cost and sales pressure to market a competitive product),
- Water supply (problems and costs of wastewater treatment) and
- Environmental protection groups (the effects of synthetic musk fragrances on the natural world).

All of the news tickers were created with the help of a Google search. The search term *musk fragrance* was combined with a different second term, e.g. *wastewater treatment*. Quotes from the first 20 hits were selected and put together on one sheet of paper (Marks et al., 2010).

Two separate groups of 2-4 students receive identical news tickers, so that all four perspectives are repeated twice in the overall group. Later, it becomes clearly visible that totally divergent news spots can arise from groups using exactly the same information sources. It also turns out that using a second search term in Google adds a completely different perspective to the topic in the news clips. This decision might also have arisen through the choices of an individual journalist, whether purposely or coincidentally. In the final phase, the pupils present their news spots and evaluate the contributions of the other groups. The discussion focuses on the believability of the content matter, the presentation's (un)convincing nature and the showmanship level of the overall production.

Generally, the created news spots reveal extremely intense examination of the news tickers by the pupils. The groups evaluated the information which they had gathered and then shortened it into a news article form. Every report was evaluated by discussion with the class. The participants recognize the problematic nature of the exercise early on. They tend to quickly connect not just the ulterior motives behind the various perspectives, but also the exaggerations and omissions used in media reports, to the final products.

In the discussions at the end of the exercise, the following factors were named by the pupils: cost pressures on the producer, consumer wishes, consumer disinterest, job security, manufacturer lobbies, lack of legal requirements to list all product ingredients, foreign importation of goods, the function of advertising, etc.

The following excerpt from a group interview after the classroom session (Marks et al., 2010) makes it clear that pupils were actively engaged in the problems of the situation:

(T): Would you vote for a political party which would spend 5 million on wastewater treatment plants?
(S1): Yes! But not if jobs would be lost by doing so.
(T): Are wastewater treatment plants the only solution to the problem? How can we take this problem in hand otherwise?
(S1): Either use another fragrance and don't use as much of it, or avoid the by-products.
(S2): Then I would choose another shower gel!
(S3): Unfortunately, fragrances are everywhere. There are thousands of other people who will still buy these products.
(S4): The substances are not represented by the info printed on the container.

(S5): You could buy products without fragrances. There used to be stuff without scent additives.
(T): Renovating or building new wastewater treatment plants would cost 3-5 million euros. Who should carry the costs?
(S5): The nation.
(S1): New compounds should be researched!
(T): Who is interested in this?
(S1): Shower gel producers could also do something useful.
(S6): We need to make it clear to the government and people that research can also save money. Fewer people get sick, one has lower costs and healthier citizens.

The different groups of learners described in the case study by Marks and Eilks (2010) showed wide-ranging cognitive levels of reasoning ability, especially when the conversation was steered in a direction suggesting solutions to the problem. The idea of total abstinence from fragrances can be viewed as somewhat naive. However, other arguments showed that the learners had begun to develop a differentiated position and that they had weighed the possibilities of actually carrying out their ideas. The students were very able to actively step into different roles (consumer, manufacturer, etc.). This allowed them to recognize that a ban on specific substances was not a panacea for solving the problem with fragrances. They understood that such legal actions as requiring a list of ingredients on all products are very difficult to bring about. All of them thought that this was a necessary step to take. However, they realized that this also was not a one-step solution, since consumers normally have difficulties understanding such information even if it is printed on the packaging.

With respect to the more general goal of the lesson plan, the reflection also focused on the process of news production. It was astonishing (even for the pupils) how different the stories from two separate groups can be, even when they present the same topic. This was also abundantly clear how different the ‘journalist’ group functioned as a filter of the presented information. However, it also became obvious how different perspectives become when the problem of cosmetic musk fragrances has a second search focus. The role of the journalist/editor was vividly underpinned in this exercise.

Advertising as a case

Advertising can serve as a third example of filtered information. Very little information on the use of advertising in science education can be found in the literature. In the case of Germany, a thorough literature review of educational journals from all available domains showed that advertising is primarily a topic of language education (Belova & Eilks, 2014b). All of the literature reveals a lack of perspective with regard to factual content and its reliability. Although terms like “misleading claims” do appear, they are not connected with reflection upon the use of any scientific information and background.

If mentioned, advertising in science education is only suggested as an introduction to a certain topic, a data-provider for tasks, or a contextualisation for experiments where claims must be experimentally tested (Belova & Eilks, 2014b). Scheibe and Rogow (2012) provide rough teaching ideas for advertising in the science classroom in their book on media literacy. Namely, they suggest examining advertising and other media either in relation to the experimental testing of scientific claims or to the image of science. McSharry and Jones (2002) also suggest advertising's potential for science education and conclude that it is a very fruitful medium in the science classroom, but they do not recommend specific teaching ideas. In most papers, advertising is only used as a tool to contextualize science learning. Reflection on advertising itself is rarely put into question. Examples of concrete activities for more elaborate reflection on advertising are rarely provided (for examples see Burrows, 1997; Kahn, 2005; Müller & Vogt, 2014).

Very few ideas go further. Stuckey et al. (2012) described chemistry lessons based on sweeteners, in which students are supposed to create an advert themselves, then reflect upon the role of the scientific information involved with respect to a certain target group. Inspired by this case study and based on a broad literature review, Belova and Eilks (2014a) suggested that scenarios which combine the motivating aspect of ads with learning about whether and how science-related information is used in advertising are of a great potential for general educational skill development. This approach was also inspired by the idea of learning about filtered information.

A socio-scientific issues-based approach to advertising (Sadler, 2011) including the consideration of the idea of filtered information suggests analysis of how science and technology-related factual content gets into ads. Such reflection concerns the intention of using science-related information in advertising to support claims. It also addresses the analysis of how advertising may contribute to misleading or suggestive advertising, namely by inclusion of truncated, falsified or even false scientific information. A thorough socio-scientific, skills-oriented perspective is also suggested. This perspective puts the interaction of science and technology with advertising itself into focus. It questions the transfer of information about science and technology into advertising forms. The difference making this role most relevant for multidimensional media literacy is the fact that advertising itself, its development, and the principles behind it are explicitly addressed and connected to scientific content. Stuckey et al. (2012) and Belova and Eilks (2014a) have already suggested chemistry education activities in which the students themselves are encouraged to create advertising. This forces them to question the roles played by subject-related information, including what effects they can (and should) have when addressing a specific target audience.

Further pedagogies for and case studies of the use of advertising in science education have been suggested by Belova and Eilks (2014a), based on the lesson plan published by Stuckey et al. (2012). One of the pedagogies developed within this framework is the “advertising method”. Students receive pre-selected information on a product. The first step is to sort it into positive and negative information groups, then into scientific-technical, economic, etc. groupings. Students in small groups then create ads based on their analysis of the information.

They must select the most promising information set concerning a specific product for a certain target group. During the presentation of the ads, the students collectively reflect on which advertisements were the most convincing and for what reasons. They discuss whether the inclusion of science-related claims is reasonable in advertising for a specific target group and ask whether this might different for other different products or target groups. The practical implementation of this lesson plan has shown that such activity is intrinsically motivating and leads to intense discussions. One example on natural cosmetics is shown in Figure 7 (Belova & Eilks, 2014a).

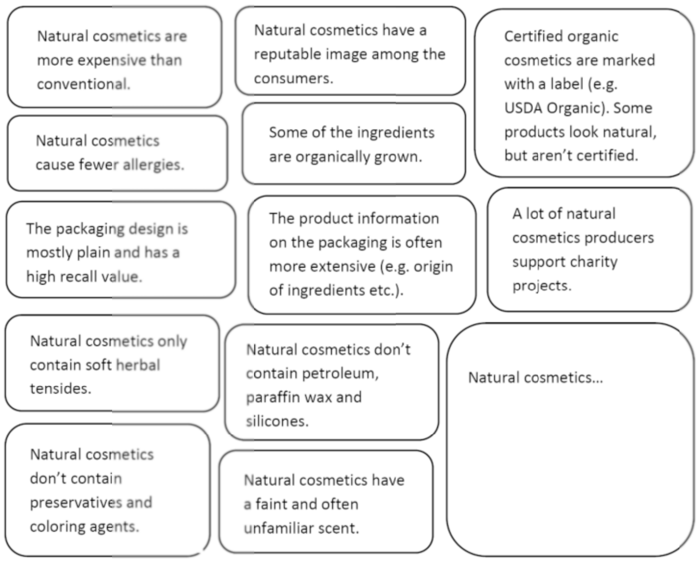

Figure 7. Possible pre-selected promotional information about natural cosmetics. The students evaluate the statements for their suitability for advertising. First, all negative or potentially negative statements are sorted out. Then the positive (or apparently positive) statements must be selected with regard to the target group

A second method suggested is termed “reflecting slogans”. Here the students receive a selection of authentic ad slogans for a certain product. The students evaluate these slogans using three criteria, namely credibility, attractiveness, and the advertising’s relationship to the scientific information behind the product. The students quickly realize how different perceptions of various advertising slogans are. Discussion is initiated through slogans which are allegedly based on scientific claims or claim that address scientific thinking. The question is also asked which role science-related information plays, how it is selected and displayed, and whether it affects the credibility and/or attractiveness of specific advertising in a positive or negative way. An example of this method (natural cosmetics) is given in Figure 8 (Belova & Eilks, 2014b).

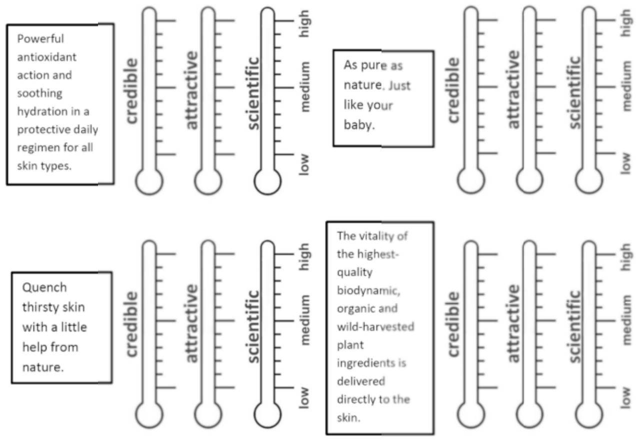

Figure 8. Advertising slogans for natural cosmetics (excerpt from a corresponding worksheet). The students evaluate the credibility, attractiveness and science relatedness of advertising slogans

A combination of different activities covering advertising in science education was also published for a case study on cosmetics (Belova & Eilks, 2014a). In this lesson plan, advertising is first used as an authentic and motivating introduction to the topic, but also serves as a starting point for scientific inquiry. The students are confronted with slogans like "pH-neutral" or "skin friendly" and have to discover their meaning through different experiments. Slogans contextualize scientific inquiry on cosmetic products. Finally, claims like "pH-neutral" and "skin friendly" are examined to see whether or not they are scientifically reliable for cosmetic products and why they were selected. During the lab work phases, the students produce their own cosmetic product, a body lotion. At the end of the lesson plan, the pupils must develop their own advertising campaign for their product. Before doing this, the students watch different TV spots on related products. The ads are examined with the help of a list of criteria.

These criteria raise the students' awareness of scientific aspects in advertising and help them to set the priorities for their own advertising. At the end, the participants produce their own ads and compared them, before discussing them as has already been suggested above.

CONCLUSION

All of the lesson plans discussed above focus on the use of scientific and science-related information in society. Joint educational models have been suggested to justify learning about the use of science-related information in authentic, non-scientific societal practices. Connecting the models in Figures 1-3 with the idea of mimicking authentic societal practices of information transfer within society proved to be very motivating to the students in the numerous case studies carried out basically at the lower secondary schooling level to test and evaluate them. This held true for exercises mimicking public discussions, decision making processes, news media creation, and advertising. At the same time such teaching units allow chemistry education to contribute to relevant general educational skill development (e.g. Burmeister & Eilks, 2012; Marks & Eilks 2010; Stuckey & Eilks, 2014).

The pedagogies and lesson plans suggested in this paper allow pupils to learn about different examples of socio-scientific information handling, both by individuals and society at large. A meta-reflection exercise included as part of the units, which explains the information filtering model, can help the students to better understand the mechanism behind information transfer. Student feedback collected during the test cases provides initial evidence that the participants had become increasingly reflective and critical when examining the topic (Burmeister & Eilks, 2012; Eilks, 2002). Exactly these features have been described as prerequisites for modern, relevant chemistry teaching (Elmose & Roth, 2005; Hofstein et al., 2011, Sjöström, 2013; Stuckey et al., 2013).

Some of the students explicitly stated that knowledge of how information transfer works can strongly influence readers/listeners. This includes not just how the information comes across, but also the impact of the actual information itself (Eilks, 2002). In this sense chemistry education has a chance to become increasingly capable to contribute not only to scientific literacy, but also to critical scientific media literacy.

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11. MAKING CHEMISTRY EDUCATION RELEVANT THROUGH MASS MEDIA

In today's society, mass media plays an important role in our life. In addition to school education, people receive scientific knowledge from mass media to a great extent. Within chemistry, the information, for example, concerning food chemistry, crime investigation, environmental toxins and local mining issues, pervades mass media. Today, all the above-mentioned issues are termed socio-scientific issues (SSI), which are seen as suitable contexts to promote scientific literacy and citizen education in the global age. In addition to the importance of noticing the emerging SSI in mass media, both of SSI and media have been found useful in enhancing students' learning in sciences, especially at the moment of facing the present phenomenon concerning students' low interest in science revealed internationally, in particular among developed countries (e.g. Sweden). Therefore, it is a major task now for us, as science educators, to put effort on motivating students' interest in science, and we believe the combination of SSI and mass media can enhance students' interest through making science relevant. In this chapter, the importance of SSI-based teaching linking to the meaning of relevance is introduced as a vision that science teachers need to be aware of and develop further. Further, we argue why mass media can contribute to making chemistry education relevant for students based on research evidence. Two examples of SSI-teaching approaches, based on local SSI topics discussed in mass media in Taiwan and Sweden, are presented to benefit teaching practices. The implication to teacher education is also discussed.

INTRODUCTION

The importance of making science relevant for students has been addressed differently by science education researchers during the past 60 years, which has been pointed out in a thorough review on the meaning of 'relevance' of science education (Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013). However, the declining interest in science subjects and in pursuing science as careers in the majority of developed countries still is at hand today (e.g. George, 2006; Stuckey et al., 2013). People might ask why students' low interests in sciences and pursuing sciences as careers still remains, even though making science education relevant has been discussed and emphasized over the past century in research literature and curricula in different countries.

I. Eilks & A. Hofstein (Eds.), Relevant Chemistry Education – From theory to practice, 205–218.

Our answer to this question is that the meaning of relevance might be perceived differently by different individuals. In other words, when teachers try to work on making science relevant, students' meaning-making on relevance might be various. Meanwhile, teachers' own beliefs, understanding and action on making science relevant in teaching practices also play an significant role as well (e.g. Goodman, 1988; Pederson & Totten, 2001).

In the reviewing work done by Stuckey and colleagues (2013), three dimensions of making science education relevant are disclosed:

- Relevance for preparing students for potential careers in science and engineering,
- Relevance for understanding scientific phenomena and coping with the challenges in a learner's life, and
- Relevance for students becoming effective future citizens in the society in which they live (p. 8).

These three dimensions of how to make science education relevant for students might contribute to explaining why students' declining interest in sciences is still an unresolved problem today. In other words, the reason might be that teachers' views and/or teaching practices on making science education relevant is still focused on the first dimension and that is to 'prepare students for potential careers in science and engineering.' Of course, further research is needed to have evidence to support this assumption concerning teachers' view and/or teaching practices on making science education relevant, but it is not the main point of this chapter. Instead, this chapter aims to address the importance of endeavoring on the 2nd and 3rd dimensions of making science education relevant and the situation of students' low interests in sciences is hoped to be improved.

THE IMPORTANT ROLE OF SOCIO-SIENTIFIC ISSUES FOR CHEMISTRY EDUCATION

Today, the remaining low interests in sciences in developed countries make science educators reconsider again how science is actually taught in school and what picture of science is eventually conveyed to students. The international ROSE (Relevance Of Science Education) study has shown that 15-year old students in developed countries found many of the themes and questions of science important, but at the same time, they rejected to choose science and technology as potential future careers (Oscarsson, Jidesjö, Strömdahl, & Karlsson, 2009). Even though having more scientists and engineers in a country can promote the economic growth in a country, based on the 'macro view' of scientific literacy mentioned in Laugksch (2000), we all know that the goal of science education in school is not only to educate and recruit the next generation of scientists and engineers (Hofstein, Eilks, & Bybee, 2011). An aim that is equally important, or we would argue, perhaps even more important, is to equip individuals with sufficient knowledge and skills and make them become scientifically literate and responsible citizens, which is in line with *scientific literacy for all* addressed in the 1960s to 1970s (DeBoer, 1991; Stuckey et al., 2013) and entails also the possibility for students to be able to perceive science as something they can relate to. Even if students do not choose science as a career, they should be able to use scientific knowledge or scientific thinking in their decision-making.

Although there are different opinions on what abilities a scientifically literate person would need to have and how to achieve the acquisition of those abilities (Shamos, 1995), there is a consensus among science educators that scientific literacy is important. Furthermore, the problems of relevance of current science education in many countries necessitate a discussion about how to achieve a relevant and meaningful science education which can facilitate the spread of scientific literacy (Stuckey et al., 2013). To make school science more relevant for educating young people living in the society of today and tomorrow, many authors suggest that some of the solutions may be found useful by increasing contextualization of the content (Nentwig & Waddington, 2005), relating more to societal issues (Hofstein et al., 2011) and providing the link between science and modern technology (Aikenhead, 1994), connecting to socio-scientific issues with ethical implications (Zeidler, Sadler, Simmons, & Howes, 2005), and conducting inquiry-based science education (Abd-El-Khalick et al., 2004). Here we argue that all the above-mentioned approaches of increasing contextualization are in conformity with the field of socio-scientific issues (SSI) emerging in science education for decades and tightly linked to the 2nd and 3rd dimensions of *making science education relevant* pointed out by Stuckey et al. (2013). In another review article on using SSI in teaching sciences, different purposes of using SSI have been discerned, for example, helping students to transfer knowledge and skills learned from school to real contexts as well as promoting students' learning interests in sciences (Chang Rundgren & Rundgren, 2010). Therefore, in an effort to confront the remaining unpopularity of the subjects of chemistry and physics among students (e.g. Hofstein et al., 2011), SSI-teaching approach is a valuable tool for teachers which needs to be promoted more in chemistry and physics education.

MASS MEDIA AS AN EFFECTIVE RESOURCE FOR TEACHING SOCIO-SCIENTIFIC ISSUES IN CHEMISTRY EDUCATION

In the world of today, mass media is the main resource for citizens to receive everyday information and get involved in societal debates. Contemporary sciences and science in social debates are often communicated with citizens via mass media. For example, the Nobel Prize winners' research work, the outbreak of new diseases in some countries or areas, the discovery of new medicines to treat diseases, environmental toxins, and food safety, are all topics that could be found in mass media, for example, on the Internet, in newspapers, and in special magazines. With a focus of chemistry education, environmental issues and food safety problems have been shown to be popular topics among young students, since these issues could be heard, seen, or experienced by students, which makes the issues feel familiar and important to learn and discuss (Chang, Yeung, & Cheng, 2009). In science education, environmental and food safety issues that can demonstrate how science and technology interrelate to our society are also categorized as SSI.

Research has shown that SSI can promote students' learning interests in sciences as well as achieve the goal of scientific literacy (Chang Rundgren & Rundgren, 2010). In addition, Klostø (2001) has shown that SSI contexts could offer eight specific content-transcending topics under the four main headings of science as a social process, limitations of science, values in science, and critical attitudes, to achieve the important goal of "science for citizenship." In this chapter, we want to illustrate that using SSI-based teaching is a good way to promote students' learning interests in sciences by making science relevant with the consideration of the individual, societal and vocational dimensions in the model of relevance proposed by Stuckey et al. (2013), and SSI discussed in mass media are good teaching contexts to start with.

New visual media and new ways of using media (e.g. interactive media) lead to new ways of learning and a change in conditions of learning (Kress, 2003). For the young generation of today, accessing and using ICT and media technology as such are not the biggest challenges. People who have access to media technology from an early age have been called 'digital natives' (Prensky, 2001). Rather, the challenges consist of dealing with the flow of information and becoming proficient in analyzing and evaluating messages contained in media in a competent way. The importance of media to the younger generation of today's society has been emphasized by several authors. Moreover, Buckingham (2003) states that:

> The media are undoubtedly the major contemporary means for cultural expression and communication: to become an active participant in public life necessarily involves making use of modern media, The media, is often argued, have now taken the place of the family, the church and the school as the major socializing influence in contemporary society. (p. 5)

From this point, it is possible to draw the conclusion that media is such an important aspect of modern life, especially for young people, that it needs to have consequences also in the science classroom. Connected to this, there are major challenges in terms of how to best access and navigate in the vast media landscape, including an increasingly varied range of sources (McClune & Jarman, 2012; Buckingham, 2006). The suggestion by Roth and Lee (2003) shows that educators need to think of both science teaching and learning in terms of changed participation in collective praxis communities (e.g. web-based chat forums) rather than as individuals reproducing facts and theories, also challenges the way teachers scaffold and assess students competencies at different levels. It has been emphasized that science education must prepare our students for life in the postmodern media landscape and thereby contribute to the public understanding of science in media (McClune & Jarman, 2012). All the above-mentioned statements support the importance of using mass media in educating the next generation, and science/chemistry education is no exception.

THE NEED OF DEVELOPING STUDENTS' SCIENTIFIC MEDIA LITERACY

Based upon the value of using SSI in mass media to teach chemistry in school to promote students' learning interests, our next step is to delineate a vision of science education in mass media society. In this section, as science educators, we would like to express that developing *scientific media literacy* is a goal science educators ought to aim for. In the following section, scientific media literacy will be defined further.

There are many definitions of scientific literacy, and different views of what competencies and knowledge a scientifically literate person would need to have (e.g. DeBoer, 2000; Laugksch, 2000). One of the most influential authors in the scientific literacy field is Jon Miller, who regards scientific literacy as a multidimensional construct. Miller (1983) defined scientific literacy as being constructed from three main aspects: (1) an understanding of the norms and methods of science (i.e. the nature of science); (2) an understanding of key scientific terms and concepts (i.e. science content knowledge); and (3) an awareness and understanding of the impact of science and technology on society. But why do we need scientific literacy? Laugksch (2000) identifies two perspectives on the aim of developing scientific literacy. First, from what can be called a macro perspective, there are macroeconomic interests of the nation's need for educated scientists and engineers. Other reasons that can be formulated from a macro perspective relate to the role of science in society and of the need in a democratic society for people with knowledge about science. An important aspect is also that people with scientific literacy can contribute to public debate and decisions in society, thus preventing society at large to be too dependent of an elite group of experts who possess scientific knowledge. Second, from a micro perspective, scientific literacy should also contribute to enhancing the lives of individuals, in the form of possible carrier choices, the individual's ability to make informed decisions about e.g. health issues, and esthetic, cultural and intellectual experiences.

How many science-related issues are presented in mass media? In the SLiM (Scientific Literacy in Media) study conducted in Taiwan (Rundgren, Chang Rundgren, Tseng, Lin, & Chang, 2012; Tseng, Chang, Chang Rundgren, & Rundgren, 2010), the occurrence and frequency of scientific terms in news articles were analyzed. Scientific terms were defined (operationalized) in the study as terms occurring in the indexes of science textbooks for lower secondary school (representing a level of science that all citizens have studied). In the scientific literacy-test developed in the study, multiple-choice questions were constructed based on the most frequently presented scientific terms in news articles, and the alternatives for people to choose were based on terms co-occurring in the same news articles. In line with what have been revealed in earlier studies on scientific terms in media (Hopkins, 1925; Martin, 1945), the subject area of biology and life sciences appeared most frequently in the media. The second most well-represented subject area in the Taiwanese news was earth sciences (Rundgren et al., 2012). It is not hard to understand the importance of being able to decode and understand the meaning of scientific terms in media, which is in line with the ideas expressed by

Millar and Osborne (1998), who have called for a science education enabling students to read and understand science-related news in the media. In our view, the goal of developing *scientific media literate citizenship* is possible to achieve via SSI-media-based teaching.

How can mass media help teachers to develop students as scientifically media literate citizens? A controversial issue of wolves and wolf hunting discussed in media in Scandinavia has been used in SSI teaching in Sweden (Eriksson & Rundgren, 2012). The wolf is a native predator in Sweden and Norway. However, since the wolf compete for the same pray as human beings, and moreover, tend to attack livestock (especially sheep and reindeers) and hunting dogs, wolves have been hunted for centuries in Sweden, almost into extinction. In later years, however, the number of wolves has begun to increase as an effect of Swedish policy of wildlife preservation. There are significant differences in different individual's willingness to share habitat with wolves in Scandinavia. This controversial media issue has been used as a starting point to discuss ecological, economic, sociological, political, cultural and ethical aspects of this SSI among upper secondary students in science teaching.

As we know, mass media tends to 'make and sell' stories in different way based on the audience. Further, there is, according to Kress (2003), a need to conduct research about how knowledge and values reach young people of today, and in what ways they can be equipped with skills to interact with media in a critical and enlightened way, not least in the light of their use of social media and their exposure to commercial messages. Klosterman, Sadler, and Brown (2012) have made a case study of mass media as a tool in science teaching. Their results indicated that students focused more on the scientific subject content than on any critical discussion about the messages that was communicated in the media. The National Association for Media Literacy Education (2014) proposes four important key competencies or aspects of media literacy: the ability to access, to analyze, to evaluate, and to create media content. We regard these four key competencies as a fundament also to scientific media literacy. Above this, scientific media literacy also relate to dimensions of scientific literacy, based on Miller (1983) we discussed earlier in this chapter. Combining the aspects of scientific literacy and media literacy presented above, we propose that scientific media literacy embraces two domains of knowledge and skills (Figure 1). In the domain of knowledge, scientific literacy plays the main role, and the four competencies of media literacy represent the skills of scientific media literacy. For example, when individuals access a news article related to science, they need to have knowledge about the scientific terms and related concepts to understand the news. To be able to analyze the scientific statements in the news article, in addition to scientific terms/concepts, people also need to know how scientific knowledge is generated. Furthermore, all the dimensions of scientific literacy are included when people need to evaluate science-related news and further to create science-related media themselves.

Since evaluation and creation relate to value judgments, knowledge about the impact of certain science and technology on society is strongly needed.

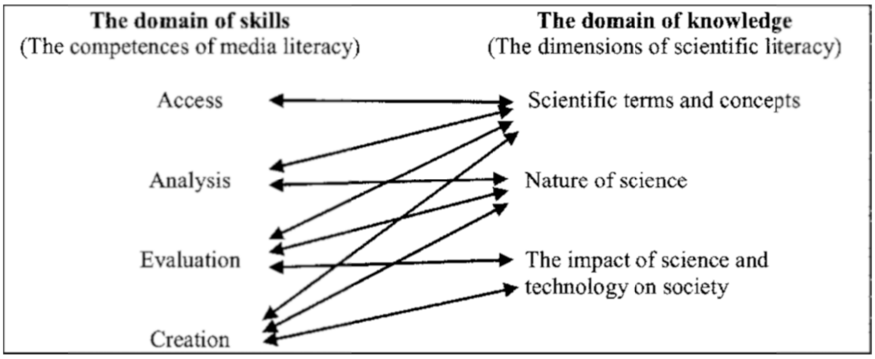

Figure 1. The aspects of scientific media literacy

EXAMPLES OF SSI-MEDIA-BASED CHEMISTRY EDUCATION

In the following section, we want to provide some examples from two different cultures to show how SSI-media-based teaching with a focus of chemistry education can be implemented.

In the EU, the pan-European regulation for the use of chemicals in society, REACH (http://echa.europa.eu/web/guest/regulations/reach), can provide a departure for chemistry teaching which relates to authentic issues faced in present-day society. REACH is a regulation of the European Union, adopted to improve the protection of human health and the environment from the risks that can be posed by chemicals (European Chemicals Agency, 2014). To raise young people's awareness of the use of chemicals in different products, the possible health risks, and the control systems in place to test chemicals in use, are in our eyes important goals of contemporary chemistry education. Concepts such as *concentration* and *toxicity* are important intellectual tools for the students to understand issues relating to the use and spread of chemicals. Possessing some knowledge about the legislation relating to chemicals and safety is, in our eyes, also part of citizen education for the future. In line with the ideas outlined above, there are also possibilities to make chemistry education more relevant for young people through using real-life issues such as spread of environmental toxins and food safety. Here, we provide two examples of two SSI teaching units relating to food safety and toxins in food, one from East Asia and one from Northern Europe.

In different countries, different food cultures exist. Selling drinks/juice in small street shops or eating different kinds of meat balls is quite common in Taiwan as well as other countries over the world. For example, one kind of meat ball called '貢丸' (Gong Wan in Taiwanese) is popular to cook with soup (Figure 2) and people can find this kind of meat ball in markets in Taiwan.

Figure 2. The meat ball 'Gong Wan' in Taiwan (Photo provided by Annie Eriksson)

During the year 2013, there was a series of food safety problems disclosed in Taiwan. The excessive use of food additives (i.e. sulphonamides) and high degree of antibiotics (i.e. chloramphenicol) were found in the aforementioned meat balls sold in the markets. Besides, illegally added industrial grade salt was also found. All the food safety issues conveyed in the news media become 'good' contexts for teachers to teach chemistry in school at secondary level. For the lower grade of students, they learn how science can help people, but also hurt people, and this can be further linked to nature of science (NOS). Different SSI topics can be discussed in classrooms to engage students' science learning. In addition to science, as we mentioned at the beginning of this chapter, moral aspects are equally important for students to develop from both school and family education, and the food safety issues caused by immoral companies' owners are, again, 'good' examples to discuss morality with students and develop students moral values.

The EU FP 7 project PROFILES, aims to make science relevant by providing context- and inquiry-based science education. A 3-step teaching model was suggested in the PROFILES project (Holbrook & Rannikmae, 2010) with the steps of (1) contextualization, (2) de-contextualization, and (3) re-contextualization. By using the food safety issue and the PROFILES 3-step model, a good example of making chemistry education relevant through mass media was developed (see Table 1).

Another example of SSI-media-based teaching concerns environmental toxins in fatty fish from the Baltic Sea, which has been highlighted in media in Sweden. The starting point of the teaching unit was a documentary film shown on Swedish television which revealed cases of illegal sales of fatty fish containing environmental toxins exceeding the EU limits from the Baltic Sea to other EU countries. A more detailed presentation of this module is also available in German (Rundgren & Eriksson, 2014). A six-step systematic SSI-teaching module is presented here (see Table 2).

Table 1. The examples of PROFILES 3-step teaching model to teach food safety issue

Steps	Activity	Time cost
Contex-tualization	The context of food safety issue from mass media can be addressed to students. Providing students with some news from mass media concerning the meat balls issue and stimulating students to come out with questions in groups concerning the food safety issue. The questions might be: How to make meat balls? What are the ingredients? What are the additives usually added to meat balls? What are the functions of the additives? What are the illegal industrial chemicals found in the meat balls in the news? What are the side effects of these additives? How to test the additives of meat balls? Can we compare the 'good' and 'bad' meat balls?	*45 mins*
De-contex-tualization	From the questions generated by students in the first step, teachers can let students to work on finding out the answer themselves in a group work. Through searching on the Internet and/or contacting scientists, companies or teachers, students will be able to come up with the answers themselves. Students can bring their information to the classroom and discuss with their group members in one lesson. When conclusions can be made, students can present their findings in the classroom. Otherwise, a second lesson is needed.	*45-90 mins*
Re-contex-tualization	After the inquiry process and the conclusions made from their questions, students can be guided by teachers to discuss more issues like: How can we be aware of the meat balls available in the market are safe to eat? If you are an officer working for the government or the president of the country, how could you ensure the food safety? The last step here is mainly to induce students to think further on how to develop themselves as responsible citizens. Also, having a possibility to make students have a role-play thought to discuss policy.	*45 mins*

In the Baltic Sea, the levels of dioxins have been found high in certain species of fatty fish, such as Baltic herring and wild salmon. The dioxins are lipophilic persistent organo-chlorine compounds that are considered to impose a serious health threat (including cancer, immune and nervous system disorders, liver damage, and sterility) to humans and other species. To ensure the health and safety of EU consumers, the European Commission has since 2002 applied regulations setting maximum levels of dioxins in food. The consequence of this legislation is that any food that exceeds the maximum levels is not allowed to be marketed in the EU. Therefore, fatty fish (mostly herring and salmon) from the Baltic Sea is no longer allowed to be sold on the EU market. However, Sweden, Finland and Latvia have currently an exemption from the EU dioxin legislation for certain fish species from the Baltic Sea that allows national marketing (but not export) of fish that exceed the threshold level for dioxin. Since 2012, Sweden has in fact a permanent exemption, permitted by the EU, based on reckoned well-communicated recommendations from the Swedish National Food Agency (the central administrative authority for matters concerning food) to certain risk groups (i.e. children, pregnant women and girls of fertile age, and presumed high consumers) in the Swedish population.

According to the Swedish government, the exemption from EU legislation is of national importance to provide job opportunities and keep rural coastal areas livable, and also to protect Swedish traditions of eating fermented herring. However, the decision to adopt a permanent exemption is controversial. Public surveys have shown that, despite communicated recommendations from the Swedish National Food Agency, a majority of the Swedish population lack awareness of vital parts of the recommendations about consuming fatty fish from the Baltic Sea. In fact, the Swedish National Food Agency (2011) is critical to the decision of having a permanent exemption and concludes that thousands more of children and women in the Swedish population are put at risk to exceed the threshold level for dioxins. We believe that this authentic societal issue is a good example of a suitable context for promoting the students' abilities to make arguments upon, to discuss and make informed decision about a multidimensional open-ended controversial issue.

To obtain a systematic way of dealing with SSI in a classroom setting, we have developed an easily accessible six-steps instructional model for teachers to follow (Table 2). The instructional model was inspired by a cross disciplinary SSI teaching approach, named 'Post it' (Chang Rundgren, 2011). Under the development of the instructional model we emphasized that the six steps procedure should be as simple as possible to follow and easily incorporated as a separate teaching unit into any kind of science class.

Table 2. The examples of PROFILES 3-step teaching module to teach environmental toxins in fish from the Baltic Sea

Steps	Activity	Time cost
Contex-tualization	Step 1: The teacher present the specific SSI case, its scientific content and necessary instructions of the SSI implementation to the students. The question might be: Do you agree or not agree that Sweden should have a permanent exemption from the EU regulation for dioxins in fatty fish from the Baltic Sea?	*60 mins*
De-contex-tualization	Step 2: Students search for further information and formulate arguments. When the SSI has been presented, the students are provided with information material and web links to national agencies, NGOs etc. The students (in groups with 3-6 students in each group) search information and start to discuss the different possible perspectives of the issue and formulate as many arguments with supporting reasons as possible. Two-colored sticky notes (post its) are handed out to the students to write their arguments (supporting reasons). The teacher should instruct the students to only write one argument on each sticky note and to use different colors to separate the 'yes-' and 'no-arguments' or 'right-' and 'wrong-arguments'.	*60 mins* + homework
	Step 3: Students categorize arguments into different groups. When the students have written down the arguments on sticky notes, they are asked to stick them on a whiteboard and begin to group the notes and designate names of the different groups, of their own choice. The idea of this activety is to let the students visualize the multidimensional aspects of SSIs and give them an instrument to facilitate the next step when the students are conducting a group discussion.	*15 mins*
Re-contex-tualization	Step 4: Students take part in a group discussion. This step, letting the students conduct a group discussion based on their visual expressions of the complexity of the issue, is considered to be a feasible way for students to express and evaluate ideas and acquire training of collaboration and informal reasoning.	*20 mins*
	Step 5: Students make their own decision about the case. After the end of the group discussion it is time for the decision-making when the students are asked to express their opinions individually and makes their own decisions upon the issue. The teacher can design a form to be filled in individually and submitted by the students with the following main questions and tasks to be answered: Do you agree or not agree that Sweden should have a permanent exemption from the EU regulation for dioxins in fatty fish	*20 mins* + homework

Steps	Activity	Time cost
	from the Baltic Sea? Yes or No? Write down and rank the four most important supporting reasons for your decision. Describe your decision and motivate yourself as clearly as you can by an argumentative text (about 500 words).	
	Step 6: The teacher provides feedback on students' informal argumentation and decision-making and summarizes key objects of the case	*60 mins*

CONCLUSION

Mass media plays an important role in our life today and in many ways the information and debates conveyed in mass media can give relevance to school activities. How to make science relevant has been discussed during the past 60 years related to the promotion of students' learning interests in sciences (Stuckey et al., 2013). However, students' low interest in sciences in developed countries is still found in internationally studies (e.g. Oscarsson, Jidesjö, Strömdahl, & Karlsson, 2009). The reason might be that the meaning of relevance for students is diverse and varying, and therefore, teachers' beliefs, understandings and actions of working on making science relevant are consequently also diverse (Stuckey et al., 2013). Concerning teachers' beliefs, understanding and action, there is a need for more research. In this chapter, we focus on presenting the importance of using SSI-media-based teaching in making chemistry education relevant, and further, to raise students' interests in science in order to achieve scientific media literate citizenship.

Concerning all the three dimensions of relevance (see Chapter 1 in this book), the examples of SSI-media-based teaching modules presented in this chapter (Tables 2 and 3) directly cover the individual and societal dimensions. Through the first two dimensions, the vocational dimension is hoped to be created by students' involvement in SSI-media-based learning process and could pursue science careers in their future.

Further, we would like to suggest teacher educators to embed SSI-media-based teaching in teacher professional development program for both pre- and in-service teachers. It is important to make school teachers aware of the meaning of making science relevant might be different among different stakeholders, such as teachers and students. Here, the model of relevance (see the introductory chapter in this book) could be used. Then, discussing scientific and media literacy with pre- and in-service teachers are needed in this science and technology dominated information age. Engaging pre- and in-service teachers to work on developing and implementing SSI-media-based science teaching is of great importance to make teachers experience to what extent students' learning outcome could be affected. At this step, pre- and in-service teachers become researchers to investigate different teaching approaches to enhance students' learning interests in sciences, and moreover, to benefit the development of scientific and media literacy.

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12. LEARNING ABOUT RELEVANCE CONCERNING CULTURAL AND GENDER DIFFERENCES IN CHEMISTRY EDUCATION

For chemistry teaching, relevant education must contribute to students' intellectual skill development, promote learner competency for current and future societal participation, and address learners' vocational awareness and understanding of career chances. Each of the three dimensions encompasses a spectrum of present and future aspects. However, the term of relevance raises a core question for the thematic priority of this chapter. Bruner stressed the impact of culture on meaningful learning. He placed his work within a thorough appreciation of culture, which provides the children with a toolkit by which they construct not only their worlds but also the perceptions and understanding of themselves and of what they learn. We can find the question of relevance with reference to society and culture also in the work of Schwab, who suggested that any educational event involves the learner, the teacher, the subject matters, and the context or the social environment. In addition, international comparative studies like ROSE suggest that science education is differently perceived by boys and girls. For example, physics, engineering or to some extent chemistry are associated with masculine attributes, and subsequently more men study these subjects. A lot of studies in science education are dedicated to the interest of boys and girls in school science, aimed at drawing conclusions for the design of science curricula. In this chapter, we will discuss two main questions: How is the perception of relevance influenced by culture and does "relevance of science education" mean the same to boys and girls?

INTRODUCTION

According to Stuckey, Hofstein, Mamlok-Naaman, and Eilks (2013) relevance can be considered to consist of three different dimensions: individual, societal, and vocational relevance (see prologue in this book). For chemistry teaching this means that relevant education must contribute to students' intellectual skill development, promote learners' competency for current and future societal participation, and address learners' vocational awareness and understanding of career chances. Each of the three dimensions encompasses a spectrum of present and future aspects.

I. Eilks & A. Hofstein (Eds.), Relevant Chemistry Education – From theory to practice, 219–240.

The meaning of relevance was discussed by leading scholars from the field of general education, e.g. by Dewey, Freire, Schwab, Novak, and Bruner. According to Dewey (1973), the school in the past was often unable to define an understandable connection of the science learning with students' everyday life. He suggested that teaching should begin more thoroughly from the child's everyday experience (see Chapter 3 by Childs et al. in this book). Dewey (1973) claimed that unless the initial connection is made between school activities and the child's life experiences, genuine learning and growth would be impossible. However, the students in our classes differ one to another by different abilities, sex, age, social and cultural background, mother language, etc. Thus, the term of relevance raises the question: How is the above mentioned contribution of relevant education influenced by the heterogeneity and diversity in chemistry classes, e.g. in the case of different cultural background and gender differences?

Quantz (2014) claimed that due to the fact that schooling usually takes place outside of the family, the culture that is taught in school may or may not differ in some important ways from that which students bring with them into the classroom. Bruner (1996) stressed the impact of culture on meaningful learning. He placed his work within a thorough appreciation of culture, which provides the children with a toolkit by which they construct not only their worlds but also the perceptions and understanding of themselves and of what they learn. We can find the question of relevance with reference to society and culture also in the work of Schwab (1973), who suggested that any educational event involves the learner, the teacher, the subject matter and the context or the social environment. Only by taking into account these components we can develop well-organised and relevant knowledge structures with the potential for applicable knowledge in the sense of everyday coping and critical behaviour in society (Novak & Gowin, 1984).

With respect to developing countries, Knamiller (1984) discussed the relevance of science education for economic development of a society. His interpretation of the idea of the relevance of science education is directly connected to real-life effects, e.g. increases in economic growth and societal wealth. This is an idea which – under the inclusion of an ecological component – is central also to the current Education for Sustainable Development movement (Burmeister, Rauch, & Eilks, 2012; De Haan, 2006). Gilbert (2006) links the issue of relevance to the question of context-based learning and meaningfulness. He claims that the main problem with science education is that the vast majority of students does not want to study science subjects after leaving school. He suggests that this is partially based on their gloomy experiences with scientific content and contexts in their school science curricula. He also states that the perceived 'lack of relevance' among students is mainly caused by inappropriate contexts and structures chosen by most curricula. Gilbert (2006) does not differentiate between relevance in the sense of the context not fitting students' interests and the inability of science education to present material as worthy of being learned. He does, however, clearly refer to students' interests, thus suggesting that higher levels of the perception of relevance among students need to be better aligned with contexts and topics fitting the learners' needs. He also makes clear that both present and future interests must be taken into account. Regarding chemistry education, he wrote that:

> For all students, the collection of contexts used must make chemistry more relevant and enable the development of a sense of ownership of that which is to be learnt. The structure of the curriculum must be such that it, at best, resonates with students' present and anticipated interests, and, at worst, is capable of engendering interest and commitment. (Gilbert, 2006, p. 959)

Westbroek, Klaassen, Bulte, and Pilot (2005) also discussed the issue of 'meaningfulness' when trying to justify context-based chemistry education. They suggest that making science education more meaningful has three characteristics: contextualized learning, a need-to-know approach, and attention to student input. They argue that science education will become relevant to students, and thus motivating, if the content is embedded in a meaningful context as seen from the students' point of view. The learners must feel a need to know and have a chance to actively participate in the issue at stake.

As mentioned above, surveys conducted in Europe (Osborne & Dillon, 2008) among large groups of young students clearly showed that girls and boys differ in their interest in science-related topics. For example, boys showed interest in topics such as

- explosive chemicals,
- how it feels to be weightless in space,
- how the atom bomb functions,
- biological and chemical weapons, and
- what they do to the human body.

In contrast, girls showed interest in

- why we dream when we are sleeping and what the dreams might mean,
- cancer – what we know and how we can treat it,
- how to perform first aid and use basic medical equipment, and
- how to exercise the body to keep fit and strong.

Although problematic, this and similar information should not be overlooked by curriculum developers in their attempt to design science curricula catered to all students' needs and interests. A review of the literature over a period of almost 40 years revealed mixed findings regarding gender and attitudes towards chemistry. In some cases girls exhibited more positive attitude towards chemistry, and in other cases, the opposite picture prevailed. Cheung (2009) conducted a comprehensive review of the literature regarding gender issues related to chemistry education. He noted that probably the first research on gender differences in secondary school chemistry was conducted in Israel by Hofstein, Zen-Zoi, Samuel, and Tamir (1977). This study was focussed on 11th and 12th grade students using an adopted version of the Chemistry Attitude Scale originally developed by Tamir, Arzi, and Zloto (1974). The study revealed that girls had a more favourable attitude towards studying chemistry than did boys.

A meta-analytic investigation was conducted by Steinkamp and Maehr (1984). It showed that regarding chemistry education girls had more positive attitudes compared with boys. In addition, in Australia Shannon, Sleet, and Stern (1982) reported that girls found chemistry more enjoyable than did boys. On the other hand, several studies conducted in Israel by Menis (1983), by Harvey and Stable (1986) in the UK, and by Barnes, McInerney, and Marsh (2005) in Australia, revealed the opposite, namely, that the attitudes of boys towards chemistry was more positive than were those of girls.

Capturing both discussed perspectives, in this chapter we focus on influence of cultural and gender differences on relevance of chemistry education. We answer the following questions:

- How is the perception of relevance influenced by culture?
- Does "relevance" have the same meaning to boys and girls? Does "relevance of science education" mean the same to boys and girls?

RELEVANT CHEMISTRY EDUCATION AND CULTURE

Talking about culture is not very easy since there are different definitions of the word. Asking people at the street almost everybody will say something different. Someone connects culture with the tradition of the country. For other people the culture is similar to the behavior or custom of different ethnical groups. The next one sees the culture as a reflection of the religion which is predominant in one country. At last, some people see culture as something which is typical for different countries, like food, way of clothing, or spending the free time, but also activities that are common for most of the people in the certain country. Sometimes even a language of one country is seen as equal to their culture. According to Ayisi (1992, p. 1), culture is "*…that complex whole which includes knowledge, belief, art, law, morals, cultural tools, customs, and all other capabilities and habits acquired by man as a member of society*."

But also chemistry has its own culture. Aikenhead (2005) discusses that most students' worldviews do not harmonize with a worldview associated with chemistry. Thus, most students do not have the same epistemology, axiology, or ontology with their chemistry teachers and professors. Aikenhead (2005) argues that much is lost in translation between the culture of chemistry adopted by teachers and textbooks, and the culture of most students, e.g. Aboriginal students. Also Corben and Aikenhead (1997) are emphasizing the inequality between Native American cultures and Western science which creates "hazardous" or "impossible" (see also Phelan, Davidson, & Cao, 1991) border crossings for Native American students (MacIvor, 1995). Further, a Japanese cultural perspective illustrates potential difficulties for Japanese students as well. These students are holding a view of nature at odds with the Western scientific view (Kawasaki, 1990). Thus, Japanese students' sense and understanding of harmony with nature on the one side contrast with Western scientific images of power and dominion over nature on the other side.

Grosser and Glombard (2008) argue that the cultural environment in which learners grow up will be a major factor contributing to the development of critical thinking skills, as well as to question-asking abilities. But it is assumed that this depends on the topic as well. Tao, Oliver, and Venville (2013) evaluated primary science students understanding of Earth by using in-depth interviews including drawings. 38 students lived in South of China and 36 students were coming from Western Australia. All of them were between age 3 and 6. Regardless of different cultures children from the same year group constructed similar concepts about the Earth. The age 3 kids were more likely than the age 6 kids to demonstrate intuitive conceptions of a round and flat Earth. Cultural mediation was found to have subtle impact on children's understanding of the Earth.

In the past two decades, science education in the multicultural context has been studied thoroughly (Hodson, 1993; Nieto, 2000; Carter, 2007; Grosser & Glombard, 2008; Roth & Tobin, 2010). Thus, in science education in general and chemistry education in particular there are some studies concerning the cultural difference, however, it is hard to find some that are matching to the relevance model of Stuckey et al. (2013). Thus, in the following part of this chapter the separation between the different dimensions as described in the model will not be given. However, some indices will be mentioned.

Culture, learning of chemistry, and relevance

Seeing the influence of the culture through the eyes of Stuckey et al.'s (2013) model, the most important part is the societal dimension. From the literature, there are large differences between Eastern and Western countries, especially when it comes to the intrinsic part of the societal dimension. In general, the influence of culture examined from the societal dimensions' point of view means that the culture of a country influences on how the students promote their interest within science learning in general and chemistry in particular.

In East Asian countries, for example, critical thinking and promoting one's own interest is rather seldom. The tasks are mainly involving reading instruction, and students are not required to perform critical reading (Wu, 1982). For many Asian people, books are often thought of as an embodiment of knowledge, wisdom, and truth, which can be taken out and put inside the students' heads (Maley, 1983). Therefore, they are treated with reverence and great value is attributed to them. In other words, authors are considered authorities. Everything they say in print has to be correct – their opinions, judgments, and conclusions. Furthermore, Chinese learners are hesitating to ask questions, and they seldom give up on a discussion (Zhao & McDougall, 2008). Thus, students are not in a position to judge, criticize, or ask. Furthermore, Song (1995) found that in East Asian classrooms, the central duty of the teacher is to transmit knowledge and that of the students is to absorb whatever the educator has to deliver. Opposite to this is the Western world cultures, where a reader of a book, e.g. students of a school book, is expected to discover new knowledge by analyzing the author's process of reasoning and weighing the ideas and asking relevant questions. Starting from here, we can assume that students in East Asian countries see less the importance and relevance of science for their life. This point is also supported by the ROSE (The Relevance of Science Education) study, where asking students about the importance of science and technology, the East Asian students are more hesitant with the positive answer comparing to students from other cultures. Furthermore, those students are more skeptical towards the role of science and technology in society comparing to other/western world students (Sjøberg, 2005). Thus, we can assume that East Asian students do not learn to promote own interests in societal discourses, since discussing and asking question is not common. Going one step further and thinking about the individual dimension from the relevance model by Stuckey et al. (2013) and seeing the studies from the western point of view (which must not be the right one in all of the cases), the (provocative) question could be how satisfying is this culture for students' curiosity and interest. How can teaching chemistry (and teaching in general) be intrinsic relevant for the present time for Asian students in their surrounding but also i.e. in Western countries?

Many studies with a focus on culture were conducted in Israel (Tamir, 1986; Tamir & Caridin, 1993; Makkawi, 2002; Tal & Kedmi, 2006; Birenbaum, Nasser, & Tatsuoka, 2007; Reichel & Arnon, 2009; Tal & Alkaher, 2009). Israel is a multicultural state, where Arab culture is described as traditional and conservative, while the Jewish culture is achievement-oriented, individualistic, and 'Western' (Shavit & Yaar, 2001). Most of the findings from the named studies point to the large differences between the Arab and the Jewish sectors, in both achievements and cognitive capabilities in science and mathematics are in favor of the Jewish sector. Plausible explanations for this gap are cultural/traditional differences in the teaching and learning strategies applied in each of the sectors. The culture and social structure of the Arab sector are very different from the Jewish sector due to great differences in traditions, ways of living, and other cultural elements. Thus, it was found that regardless of their talent or motivation, Arab students are severely disadvantaged in terms of their learning conditions (Tamir & Caridin, 1993). This includes the discrepancy in educational resources available to Jewish and Arab municipalities in Israel as well as the differences in the teachers' qualifications in these two sectors (Birenbaum & Tatsuoka, 2007). Another probable factor is the student–teacher relationships' dissimilarity, namely the social tradition of having a high level of 'formality' in Arab schools.

Based on this, one may wonder about the teaching and learning issues which are relevant for different cultures (Dkeidek, Mamlok-Naaman, & Hofstein, 2010). As an example, Dkeidek et al. (2010) elaborated on the phenomenon of questioning and question-asking ability in the Jewish and Arab cultures as it is a core competence in science. There is a deep-rooted tradition in Jewish education, and indeed in Jewish cultural behavior, that asking and answering questions is a central form of learning and interaction. An emphasis on questioning and question-asking ability is not a new cultural phenomenon; it can be traced back to modes of Jewish learning, as evident in a variety of Jewish textual sources (Sigel, Kress, & Elias, 2007). Horowitz's (2005) discussion of a teacher training program for both Jewish and Catholic educators illustrates this well. The Jewish educators stood out (in the eyes of the Catholics) as being particularly experts in asking questions and in probing the texts (Horowitz, 2005). Moreover, Horowitz (2005) suggests that having a critique of a tradition, the ability to question freely and without inhibition, the valuing of difficult questions, are mostly appreciated. In short, it suggests a habit of mind that may be characteristically Jewish, and one worth fostering from a western point of view. Also here, we can see the differences for the relevance of chemistry for students coming from different cultures.

Culture does not only influence learning, but also teaching. Different studies show that culture is a very important and often underestimated factor on understanding science teachers' beliefs, the influence on teachers' classroom behavior and the related effects on students' learning (Markic et al., in press; Dkeidek et al., 2010; 2012). Current research revealed that teachers' instructional practices affect minority students' achievements, attitudes, and careers (Kanter & Konstantopoulos, 2010). Markic et al. (in press) confirm the differences between Arab and Jewish teachers in Israel. The findings provide evidence that in Israeli chemistry classrooms the beliefs of Arab teachers differ from those of the Jewish teachers although both groups live in the same country and operate the same educational system. More in detail: Arab chemistry teachers in this study hold more thoroughly beliefs about teacher-centered teaching and learning. The Jewish teachers are also holding these traditional beliefs, however, less strong than Arab teachers. Furthermore, Arab teachers in this study see as an objective of chemistry teaching more or less exclusively a focus on content learning. Only a minority of Jewish teachers here agree with this belief. A majority holds more or less strong a belief that learning of competencies, problem solving, or thinking in relevant contexts are the main foci of teaching.

Putting focus on religion, Aflalo (2013) examined in her study with 101 first year Arab and Jewish student teachers, the effect of the degree of student teachers' religiosity, their nationalism, and science background on their perception of nature of science (NOS). On the one side, the findings show that previous scientific knowledge or belonging to the Jewish or Arab nation barely impact the perceptions of NOS. However, on the other side, student teachers' religious beliefs, whether Jewish or Muslim, have significant impact. The more religious the student teachers, the greater weight their culture and society versus science is. Furthermore, their support of the freedom of inquiry and of the tentativeness of science decline the stronger their religious beliefs are. That is why Aflalo (2013) suggests the supporting of the liberal dialogue approach that does not fear criticizing tradition, according to which it is possible to educate to critical thought without negating religious beliefs.

Although in Israel students are coming from one country having the same political system, the studies show that one's culture influences the way of teaching and learning. Further the cultural background differences seems to have an impact especially on the societal dimension of relevance of science education by Stuckey et al. (2013) when it comes to extrinsic relevance means behaving as a responsible citizen from the Western point of view. The question may be allowed how exactly the Arab and Jewish culture influence the learning about the behavior in society (which is here the same). Additionally, the above mentioned studies show some more. Considering teachers' beliefs and their influence on students, we can also say that the influence of culture can be found in the vocational dimension in

Stuckey et al.'s (2013) model. It is to suppose that the difference in teachers' beliefs about the aims of the lesson are influencing the extrinsic relevance for the present time (passing exams), but also on intrinsic relevance when it comes to orientation about potential careers. This will be elaborated in the next section.

Culture, chemistry and relevance

Almost all over the world culture has influence not only on the method (or strategies) of teaching, but also on the importance of different subjects in school. E.g. the population of Tanzania is large, there are no attractive relevant curriculum materials, and therefore the provision of appropriate science education needs a huge effort on the national level (O'saki, 2007). Therefore, the government launched the Secondary Education Development Program and enrolment Ministry of Education and Vocational Training (MoEVT, 2010). One of the projects was the Enabling Science Learning in High schools in Rural Tanzania (ENSCIENCE) (Setter, Favrat, Mamlok-Naaman, & O'saki, 2002). One of the main goals of the project was to develop a relevant learning environment, namely, the curricula, the textbooks, and the teaching strategies, should take into account the African environment, the African child's development, the African cultural heritage, and the demands of technological progress and economic development (Yoloye, 1986). The integrated science modules which were aimed at chemistry students were designed at EPFL and at the Weizmann Institute of Science by a Tanzanian PhD students, and developed with an inquiry-based approach, related to relevant socio-scientific issues (Francis, Mtabazi, Gabrieli, O-saki, & Setter, 2012), which will be appealing to the students in Tanzania. It sounds as if in Tanzania the relevance of chemistry and science is rising. The influence on the relevance of chemistry on students is only a speculation at this point, but keeping the ROSE study in mind, hopefully explicit the vocational dimension of relevance, concerning the intrinsic relevance for the present (orientation about potential career) will rise as well. Sjøberg (2005) shows also in the ROSE study, that students in developing countries do not see themselves as becoming a scientist in comparison to other countries. The acceptance of the statement "I would like to become a scientist" is extremely low. In contrast to this, Scandinavian and Japan students in the ROSE project see themselves as a potential scientist and can imagine themselves making a career in this direction. Markic (2010) showed in her case study with German teachers that they see the difference in students' attitudes towards chemistry and towards the relevance of chemistry in students' life. While Slavic families support their children in learning science and see the relevance of chemistry for a child's future life, Arabic/Turkish families are less distinct in this opinion.

Cultural open chemistry teaching is using knowledge about the students' culture and their life experience to conceptualize learning that is conducive to their needs. The problem is, however, that it is still not clear what teachers need to know to teach in a culturally responsive way. Wallance and Brand (2012) made a qualitative study with two science teachers who primarily teach African American students in their classes. The analysis reveals that the teachers' beliefs and practices were informed by their critical awareness of social constraints imposed upon their students' identities. Furthermore, the findings show that importance of sociocultural awareness for conforming the teachers' instructions, as well as their strategies for managing the varying dynamics occurring in the classrooms. The understanding of the racial inequities is crucial to development of sociocultural awareness and is the foundation for the culturally responsive dispositions and practices of the teachers. The possibility how to change teachers' awareness considering this topic is presented in Goff, Boesdorfer, and Hunter (2012) as well as in Hernandez, Morales, and Gail Shroyere (2013). Hernandes et al. (2013) conducted a qualitative study to develop an inclusive and comprehensive model to guide the preparation and assessment of teacher candidates for culturally responsive teaching. The developed model of culturally responsive teaching contains five thematic categories:

1. content integration,
2. facilitating knowledge construction,
3. prejudice reduction,
4. social justice, and
5. academic development.

The authors discuss that the model is a promising tool for the comprehensively defining culturally responsive teaching in the context of teacher education as well as the guide curriculum and assessment changes aimed to increase candidates' culturally responsive knowledge and skills in science and mathematics teaching.

All in all, although there are not much studies and project considering the culture of students and teachers and specially focusing the relevance for science, there are still some hints that can help us in this direction. Finally, we can learn from here that the culture – also when it belongs to the minority of the students in the classroom – seems to play a role and influences the perception of relevance of the students considering science teaching in general and chemistry teaching in particular. Chemistry teachers should be aware of this fact and be familiar with the different students' cultures in hers/ his chemistry classroom.

RELEVANT CHEMISTRY EDUCATION AND GENDER

In most studies, for the sake of convenience, gender is equated with sex. In gender studies or in more feminist approaches, however, gender is seen as a sociocultural construction while sex refers to biological attributes. Some human scientists like Judith Butler (1993/2011) contradict to this conception as the socially constructed gender is dependent on the culturally biased interpretation of the sexual characteristics – body and mind cannot be separated. Gilbert (2001) argues "*for a view of sex/sexual difference as neither a social construction, nor an essential biological reality, but as a discursive construct, as something which functions symbolically, at the level of our collective unconscious, to structure our social order*" (p. 295). As we refer to other studies in this article we cannot stick to one term and definition, but try to reflect on the given one where necessary.

In the context of science and science education women are usually 'constructed' as a minority in a male dominated field. Especially the so-called hard sciences, e.g., physics, engineering, or to some extent chemistry, are associated with masculine attributes, and subsequently more men study these subjects, whereas biological sciences are regarded as feminine or ambiguous (Schreiner & Sjøberg, 2006). "*This gender symbolism informs curriculum discourses and practices which in turn reproduce and legitimise gender divisions*" (Hughes, 2001, p. 276). Interestingly, no concern seems necessary about the fact that less boys than girls choose biological sciences.

Accordingly, during the feminist movement intervention programmes were designed to increase the number of women enrolling in science courses. The first attempt was to change women/girls so that they were more like their male counterparts being successful in science. These attempts did not close the gender gap as they did not "*question the deeply gendered nature of scientific knowledge, or challenge the strongly masculine culture which characterises scientific and technological workplaces*" (Gilbert, 2001, p. 292). According to Gilbert, science had to be deconstructed. Consequently, science was tried to be taught differently in a way that "*would make it more relevant or accessible to women/girls*" (ibid.).

But when is science education relevant for girls or boys? Does "relevance of science education" mean the same to boys and girls? International comparative studies like ROSE (Sjøberg & Schreiner, 2010) suggest that science education is differently perceived by boys and girls. They are interested in different topics, interpret different aspects of science as meaningful, and have different career aspirations. Stuckey et al.'s (2013) suggested model of relevance in science education with its three dimensions will be taken as a basis here to provide answers to the posed questions. As there are overlaps between the dimensions, the individual dimension will be presented in detail whereas the vocational and societal dimension will be in aggregate form.

The individual dimension

First, the intrinsic-present viewpoint will be dealt with. A lot of studies in science education are dedicated to boys' and girls' interest in school science to draw conclusions for the design of science curricula. Concerning subjects they show that boys are more interested in chemistry and physics than girls. The older the children are, the bigger is the difference (Merzyn, 2008). This phenomenon is explained with identity construction. "*Also in the school and classroom context, young people define and communicate their identities through signs like school performance, subject preferences, behaviour in the classroom and in the breaks, etc.*" (Schreiner & Sjøberg, 2006, p. 4). Interestingly, some studies give evidence that in mono-educational settings the gender-specific attitudes and behaviours are less distinctive (Hannover, 2004). However, the validity of these findings is doubted (Faulstich-Wieland, 2004). What authors agree on is that subject interest is a key for educational choices. As long as other subjects are more interesting, a career in science remains unlikely, whether or not the students perform well in science (Schreiner & Sjøberg, 2006).

A compensation for a lack of subject interest seems to be the embedding of content in contexts making chemistry more relevant (Gilbert, 2006). Generally, girls seem to prefer other contexts than boys, mostly contexts that are personally meaningful for them. The recommendation is to design the curriculum in line with contexts that a lot of girls are interested in as this is mostly interesting for boys as well, but not vice versa (Häußler & Hoffmann, 2002). Contexts that are related to the personal life and based on the world of experience are considered as most promising. Some studies name contexts like chemistry and food, household, or hygiene (Häußler et al., 1998).

Other authors warn to use these stereotyped contexts (Faulstich-Wieland, Willems & Feltz, 2008). The latter distinguish between "*doing justice to the sexes*" versus "*justice for the sexes*" (p. 11). The first "dramatizes" the differences, which is understood as accepting and welcoming the differences of each sex. However, this involves the danger of stereotyping and dichotomising, i.e., to plan supposedly relevant science lessons for the girls and the boys. This is also the principle most research studies in science education pursue which can sustain gender differences (Kahle, 2004). The second approach – "justice for the sexes" – "de-dramatizes" sex. It is about gender equality which means seeing a diversity of differences. Teachers following this approach would be able to plan science lessons on the basis of individual students' abilities and needs, not on the basis of gender attributions. However, this involves the danger to miss gender differences and to be insensitive to the importance of gender. Faulstich-Wieland et al. (2008) suggest do dramatize first in one's own thinking, to perceive the differences, to reflect the observations, to be able to de-dramatize afterwards in the classroom, seeing what makes science relevant for the individuals.

A second viewpoint in the relevance model is the intrinsic-future one. In our science and technology driven world students need to develop skills to cope with their life in the future. PISA 2006 revealed that in average there is no significant difference between boys and girls in the science domain across countries in contrast to the gap within the genders. However, regarding the three key domains of scientific competence PISA identified boys and girls as differently skilled. "*[F]emales are stronger in identifying scientific issues, while males are stronger at explaining phenomena scientifically*" (OECD, 2007, p. 114). PISA 2012 overall confirmed gender equality in science performance. Because science was not the main focus the detailed results could not be replicated. Alarming are the differences especially in reading performance where girls outperform boys and less but also worrisome are the differences in mathematics performance where boys in general score higher than girls, especially in the beliefs and motivation section of the PISA test. Additionally, girls are less often among the highest achieving students (OECD, 2013b). Both dimensions mathematics and reading can influence science achievement depending on the pedagogies followed in the classroom and as a consequence the development of necessary skills to cope with a technology influenced life is hindered (O'Reilly & McNamara, 2007).

Looking at the extrinsic-present area of the relevance model by Stuckey et al. (2013), PISA is also informative. The results show that girls are more often represented in higher performing school programmes and tracks, and receive better grades on average (OECD, 2007). Boys tend to have a higher risk for negative school careers and behaviour disorders which make them less "*suitable*" for the school system (Hannover, 2004). More often they are early school leavers, especially in high-income countries (OECD, 2012). In the European Union "*the increase of female attainment rate in tertiary education is almost twice as high (14%) as that of men (7.6%)*" (Scambor, Wojnicka, & Bergmann, 2013). Consequently, there are more and more studies focusing on the disadvantaged role of boys in educational settings.

But so far these aspects are valid for the school attainment in general. There is no effect on choices in the science and technology field, where girls are still underrepresented. For example, in the Chemistry Olympics girls' participation is just a tenth of boys' portion (Ziegler & Stoeger, 2004). An explanation for this phenomenon is not different abilities, but among others motivational variables, e.g., a poorer ability self-concept is reported by girls (OECD, 2007). Urhahne, Ho, Parchmann, and Nick (2012) corroborate that only one out of 14 female participants had made it to the last qualifying round of the German Chemistry Olympics. A lot of factors were found to influence the success of the participants: "*Parental influences played a vital role but also intelligence, prior achievement, school grades, motivation, and emotion of the participants. The strongest predictor of success proved to be previous participation in the IChO [International Chemistry Olympiad]*" (Urhahne et al., 2012, p. 180).

Britner (2008) compared self-efficacy of boys and girls in an earth, a life and a physical science class. Girls reported higher science self-efficacy in earth science classes than boys while there were no differences in life and physical science classes. However, girls stated a higher science anxiety in the latter two areas. By an interview study – one of the rare qualitative approaches in this field – with 30 year twelve chemistry students Cousins (2007) found that boys enrolled in the subject because of enjoyment whereas girls chose chemistry because they could need it for tertiary studies, "*failing to mention any real enjoyment or passion for the subject*" (Cousins, 2007, p. 722). Also, the opinion of their friends had a big influence. Additionally, girls expressed a fear of failure choosing high level courses. Chemistry was perceived as very "*intellectual*", "*hard*" and thus a "*male*" subject (p. 724).

But it is possible to work with girls on their patterns of attributing. Ziegler and Stoeger (2004) report on an attributional training in chemistry that helped girls to improve their ability self-concept.

> Science educators who are aware of the importance of self-constructs and of their own role in facilitating the development of positive attitudes and beliefs in their students can help to ensure that all students with an interest in science are able to develop their talents and make a significant contribution. (Britner, 2008, p. 968)

It is not helpful to see underachievement as a characteristic of girls, but as "*a response to teaching environments*" (Kahle, 2004, p. 961). Furthermore, teachers should be aware of the role model they represent and which misattributions are used in textbooks (OECD, 2012). Chemistry teaching materials sometimes orchestrate gender degradation (for example see Prechtl & Reiners, 2007, Figure 1).

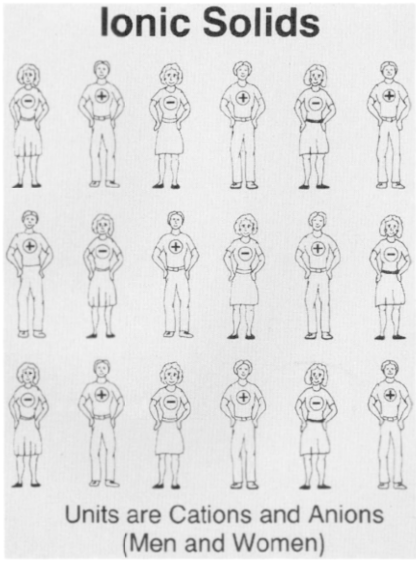

Figure 1. Analogy for an ionic solid (Fortman, 1993, p. 57)

> Specifically, a gender-inclusive science curriculum draws upon both girls' and boys' experiences, interests, and preconceptions; prioritizes active participation; incorporates long-term, self-directed projects; includes open-ended assessments that take on diverse forms; emphasizes collaboration and communication; provides a supportive environment; uses real-life contexts; and addresses the social and societal relevance of science. (Brotman & Moore, 2008, p. 983)

This leads to the last viewpoint of the individual dimension which deals with future-extrinsic aspects: to act solidary and responsibly in the future. Students should learn to act as mature citizens. According to Stuckey et al. (2013) learners "*need to understand the behaviour of expert persons in society that the students can identify themselves with actors in society and thus become able to develop own motives for action*" (p. 14). From a gender perspective society has to offer the male and female actors and the task for teachers could be to make the diversity visible. As there are role models missing in some areas for girls – women more often choose the humanities than science (OECD, 2012) – teachers have to invest more effort in this direction. The media impedes the possibility to identify with science experts as scientists, male scientists of course, are often portrayed as "mad scientists" or ignorant loners "*who are insensitive to environmental issues*" (Dalgety & Coll, 2004, p. 62). This image influences especially females who were found to favour topics and subjects with high social relevance (Reid & Skryabina, 2003). For example, the ROSE study including 18 items on environmental issues revealed that this is a more important topic to girls (Sjøberg & Schreiner, 2010).

Buck, Clark, and Leslie-Pelecky (2007) made interesting findings in their intervention study with 13 female eighth graders and eight female scientists concerning role models: "*The main reason the girls' originally could not picture a scientist as a role model was (1) role models are persons with whom they have a deep personal connection and (2) scientists are 'geeky looking' people that are too mean or too smart to be connected to them*" (p. 698). During the study the women scientists worked with the girls to establish relationships "*between girls and gender-matched role models*". Six months after the intervention the girls stated that a female scientist could be a role model for them. Central for the girls was a good personality, a personal connection and science expertise (Buck et al., 2007).

Another interesting part of the study is that the women scientists were also interviewed. In the beginning of the study their perception of a role model was tied to the science profession. After the intervention they perceived how important the personal relationships with the students were. Conclusively, being a role model and identifying with one is a reciprocal process fostering career choices.

The vocational dimension

"*The relevance of science education in the vocational dimension is composed of offering orientation for future professions and careers, preparation for further academic or vocational training and opening up formal career chances (e.g. by having sufficient coursework and achievements to enter into any given higher education programme of study)*" (Stuckey et al., 2013, p. 18).

The question is whether girls do get the same career chances as boys? Concerning mathematics performance in PISA 2012 "*girls are under-represented among the highest achievers in most countries and economics, which poses a serious challenge to achieving gender parity in science, technology, engineering and mathematics occupations in the future*" (OECD, 2013a, p. 9). Girls report less motivation to learn mathematics and less belief in their own skills which has "*serious implications not only for higher education, where young women are already underrepresented in the science, technology, engineering and mathematics fields of study, but also later on, when these young women enter the labour market*" (OECD, 2013b, p. 4). As pointed out before girls choose a career in science less often – "*a cause for concern given the skills shortages in the workplace, the generally more promising career and earnings prospects in science and technology, and the likelihood of positive spill over into innovation and growth*" (OECD, 2012, p. 14). These findings show that it is not enough to think about science teaching approaches to improve girls' access to science careers. The school has to be thought of as a whole enterprise with personal, societal, and economic implications.

The days are over that different career aspirations are assigned with less ability or biological conditions of females. Schreiner and Sjøberg (2006) found that boys and girls prefer to work with something they find important and meaningful, but especially for girls this is not a career in science and technology. Girls are more often oriented in humanities than science (OECD, 2012). Already Jones, Howe, and Rua (2000) came to the conclusion:

> There were statistically significant differences by gender for four of the characteristics of future jobs (…). More males than females wanted to 'control other people,' 'have an easy job,' 'become famous,' 'make and invent new things,' and 'earn lots of money.' More females than males wanted to 'help other people'. (p. 186)

There are different ways to interpret these findings with different consequences. The different career aspirations and priorities could be accepted or even promoted. Teachers' role would be to broaden the horizon of the students showing them which careers in science are possible, but to listen to their decisions and accept non-science aspirations. However, the decisions could be made because of low self-efficacy or anxiety (see above), traditions, parental expectations, or sociocultural aspects (BouJaoude & Gholam, 2013) which could easily be overlooked. To counteract there should be programmes and people in and out of school which encourage girls to choose a career in science, e.g. mentoring or leadership programmes. This accommodates an economic perspective. The challenge is that these measures only have a chance to be successful when girls develop strong career identities and increase their self-efficacy (Kerr & Robinson Kurpius, 2004). Short-term interventions are usually not sufficient. In school this would mean to make science relevant by being sensitive to individual beliefs, attributions, abilities, interests, backgrounds etc. with a future orientation which is an enormous challenge dependant on the respective school system, but a necessary agenda.

The societal dimension

The societal dimension addressed here is based on the idea of a scientifically literate citizen who is judicious and able to act responsibly and autonomously in society (Stuckey et al., 2013). Regarding gender we have to analyse if females or males have difficulties to find their place in society, to promote their interests in societal discourses, to learn how to behave in society or to behave as a responsible citizen. Of course this is influenced by the individual and vocational domain, e.g., low self-efficacy, underachievement, or negative school careers and inappropriate teaching strategies as well as missed or impeded career chances can hinder somebody to position oneself in society. Females and males may be exposed to different risks here described above.

A teaching approach that seems to be gender fair aiming for scientific literacy is working with socio-scientific issues and moral dilemmas chosen closely to authentic science contexts (Sadler & Zeidler, 2004; Zeidler, Sadler, Simmons, & Howes, 2005; Bennett, Lubben, & Hogarth, 2007). Gender could not be identified as a significant factor in these studies. This approach has the potential to reduce gender differences, to make science relevant for females and males and thus to fulfil the claim "*science for all*". Scientists, journalists and politicians have a special responsibility to make scientific issues accessible and understandable for citizens (Skorupinski & Ott, 2002). It has to be ensured that females and males can equally participate in societal discourse which is very dependent on how gender is constructed in a certain society. Attitudes of parents, teachers, classmates, politicians and others can increase the cultural pressure influencing personal, social and vocational choices (BouJaoude & Gholam, 2013).

Britner (2008) provides a conclusive statement: "*The full inclusion of girls and women alongside boys and men in science endeavors is not only an issue of equity, but also important for the full inclusion of talents and perspectives on science and its place in society*" (p. 968).

CONCLUSION

About twenty five years ago, Newton (1988) claimed that:

> Science teachers are increasingly exhorted to make their teaching relevant but, in general, the notion of relevance in science education seems fraught with inconsistency, obscurity and ambiguity. (p. 1)

Many articles in science education are introduced by the claim that science education (especially in the domains of physics and chemistry) is not very popular among the students (e.g. Hofstein, Eilks, & Bybee, 2011). A lot of these articles infer that students are not sufficiently interested in or motivated by science subjects (Osborne, 2003). A frequently mentioned reason is that the students do perceive science or science education as being not 'relevant' (e.g. Gilbert, 2006; Dillon, 2009). As a result teachers are asked to make science education 'more relevant' in order to get students better motivated and interested in science subjects (Newton, 1988; Holbrook, 2005). But sometimes it remains unclear what exactly is meant by 'making relevant', how to do that and what the connection is supposed to be between the different terms relevant, interesting or motivating.

Without any doubt, science is relevant for our world and the society we live in (Bradley, 2005). Many papers emphasize the importance of science keeping the wealth of modern societies and thus justifying the learning of science to be essential for a sustainable development of our future (Burmeister et al., 2012) and for active participation in society (Hofstein et al., 2011; Sjöström, 2013). From this justification all students are considered to need certain knowledge of science to become literate citizens, to be able participating in socio-scientific discussions, especially in an increasingly technological world. It is also agreed upon that modern societies need a sufficient part of the young people embarking in a career in science and engineering (EC High Level Group, 2004). Every country today needs scientists for continued technological development and to maintain the economic standards in future. But also here the question must be allowed: Does the importance of science for a technological world and the consequences of its application on the ecological, economical and societal development of our society in the rhetoric of educational policy papers mean the same as the word 'relevance' if it is used to justify science education?

Regarding gender, as mentioned above, there are science educators who believe that scientific issues are less relevant for girls. For example, Zohar and Bronshtein (2012) refer to low participation rates of girls in advanced physics classes. They claim that this is a serious problem in many countries. They conducted interviews with 25 physics teacher who taught in 25 different high schools in an urban area in Israel. One of the main findings showed that most teachers do not know what can be done to encourage girls to choose physics and to create a more gender inclusive physics learning environment. Therefore, science educators and policy makers should be aware to this problem, namely, create a suitable learning environment for both boys and girls who study physics for example in particular or science in general, including socialization and cultural factors in structuring gender roles, and equal educational opportunities of all people, men and women. However, although the research findings were mixed, the "good news" is that in some studies and in some countries and regarding some programs the attitude of boys and girls towards chemistry is equal. These are encouraging since there is great concern regarding the number and contributions of women in the sciences (mainly the physical sciences) (Kahle & Meece, 1994).

We may conclude that nowadays the issue of the relevance of learning science no longer only addresses the small percentage of students who were on their way taking up a future career in science or engineering. The focus shifted towards helping all the students to cope with their life and to understand the role of science and technology in their personal life and in the society in which they live and operate. Also, Hurd (1970) claimed that science had to be taught in a wider context than the processes of which it is formed. Contexts from everyday life and society should be used for situated learning of science and also to recognize the importance of science to understand phenomena and technology (Gilbert, 2006). However, Fensham (2004) wrote that in science programs which he investigated, there was almost no mention of the social implications and consequences of science. This is the case also today in some of the context-based science curricula where handling the context in science teaching is detached from its societal, ecological, and economic implications (Gilbert, 2006). However, decision makers in educational systems should consider the culture component in the case of educational reform which intends to introduce or implement any change in the educational system, consisting of social and relevant issues. Any educational reform needs more comprehensive approaches which take into account the many perspectives that belong to a systemic view. Only with explicating and taking into consideration the influence of the cultural background of the acting persons reform will become feasible and ready to be implemented.

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13. SCIENCE-TECHNOLOGY-SOCIETY AS A FEASIBLE PARADIGM FOR THE RELEVANCE OF CHEMISTRY EDUCATION IN EMERGING COUNTRIES

One of the main challenges for science education is to face social and cultural aspects, in order to help develop students' capacities as responsible savvy citizens in a world increasingly influenced by science and technology. The educational goal is to understand the human and social dimensions of scientific and technological practices and its consequences. Therefore, science teaching requires pertinent pedagogical content knowledge for planning and enacting new strategies, including scepticism, controversy, complexity, multiple perspectives, and inquiry. Teachers should transform everyday problems into learning situations to promote students' decision-making, argumentation, discussion and debate, moving them to more informed views about the nature of science. In most countries the majority of high school students respond favorably to science courses that encourage practical utility, human values, environmental issues, and a connection with everyday life. That is why a Science-Technology-Society (STS) approach has been selected in many educational systems and schools aiming at "Scientific Literacy for all." It is important for strengthening democracy that our citizens have an opinion and a position on socio-scientific issues, specially the controversial ones, such as pesticides, medicines, cloning, genetically modified organisms, energy issues (nuclear, petroleum, global warming), the release of potentially harmful substances, the use of hormones and antibiotics in animal production, and so forth, but also to be literate on the framework of history and philosophy of science and technology. In this chapter we discuss some pedagogical considerations about teaching and learning about socio-scientific issues in chemistry classes, especially relevant for students in emerging countries; taking into account that teachers and students interact with local and general curricula, institutions, educative policies, available technology, society, and culture.

INTRODUCTION

The relevance model developed by Stuckey, Hofstein, Mamlok-Naaman, and Eilks (2013) implies that three major dimensions must be considered in the understanding of 'relevance' of science education: individual, societal and

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vocational relevance, all of them form a broader field covering both intrinsic and extrinsic components which have value for the present and the future.

Science and technology permeate every aspect of our lives, from the most private decisions about diet, reproduction, and medical treatment, to the most public choices concerning risk, development, security, and the quality and sustainability of the human environment. Virtually every dilemma that people and governments in contemporary societies are confronted, involves demands with significant engagement science and technology. That is why approaches of Science, Technology, and Society (STS) search for meeting the history and philosophy of science and technology to anthropology, sociology, economy and even literature. As mentioned by Stuckey et al. (2013): "*Context-based (and STS type) curricula operate in a wide range of contexts in order to provide meaningful situations to support the learning of science*" (p. 22). Those curricula clarify the role of science and its related applications in the everyday lives of the pupils.

Scholars in STS, like Glen Aikenhead, ask: How do changes in science and technology affect what it means to be human? And, conversely, how do science and technology express human values? STS scholars are interested in a variety of problems including the relationships between scientific and technological innovations and society, and the directions and risks of science and technology. STS emerged from the confluence of a variety of disciplines and disciplinary subfields, all of which developed an interest in viewing science and technology as socially embedded enterprises.

Aikenhead (2003) magisterially developed STS studies' impact on education by making a full historical description of all the names that the STS approach have received since its creation. There, he also endorses Gallagher's (1971) proposition for a new goal for school science:

> For future citizens in a democratic society, understanding the interrelationships of science, technology and society may be as important as understanding the concepts and processes of science. (p. 337)

Aikenhead (2005a) published an article where he synthesized the existing research into STS science education in terms of policy making (curriculum development), student learning, and teacher orientations toward such a curriculum. He defined as the goal for science education as to "*develop students' capacities to function as responsible savvy citizens in a world increasingly influenced by science and technology*" (p. 384).

A more thorough approach in societal-oriented science education is subsumed under the term of socio-scientific issues (SSI)-based science education. This view on the chemistry curriculum is strongly connected to the STS curriculum emphasis (Eilks, Rauch, Ralle, & Hofstein, 2012), although Sadler (2009) has mentioned "*because the STS label has been so widely used, its meaning has become diffuse and activities and approaches labelled STS often do not share a common framework*" (p. 699). Nevertheless, he concedes, "*The STS movement has been very popular and successful in terms of exerting influence within the international science education community*" (p. 698).

In Stuckey et al. (2013) the relation of 'relevance' with the idea of *Bildung* and *Allgemeinbildung* on the aims of education presented by Wilhelm von Humboldt is discussed. Humans are cultural creatures: *Bildung* is part of the civilization process. *Bildung* should be seen as a precondition for developing culture and society. Acquiring *Bildung* is the process of understanding the world, which is a lifelong process. So having *Bildung* means that you are skilled in understanding, acquiring and dealing with everything around you. Klafki (1958) [for a reference in English see Klafki (1995)] developed on this a set of questions that he called Didactical Analysis where he mentioned a lot of representations used by teachers in their Pedagogical Content Knowledge (PCK) (facts, phenomena, situations, experiments, controversies, pictures, hints, situations, observations, accounts, models, laws, criterion, problems, methods, techniques or attitudes) much more that those mentioned by Shulman (1986) in his first papers on PCK.

As the 21st century unfolds, the importance of conceptualizing scientific literacy to include informed decision-making, the ability to analyse, synthesize and evaluate information, dealing sensibly with moral reasoning and ethical issues, and understanding connections inherent in socio-scientific issues is widely recognized (Zeidler & Keefer, 2003; Stuckey et al., 2013). Many science educators have reaffirmed the importance of envisioning science not as an isolated subject but understanding the role of science in relation to other areas of life.

In this chapter the authors will explore some facets of STS and socio-scientific issues related with chemistry education in their countries, all of which can be characterized as emerging. (Our understanding of the meaning of 'emerging' refer to Vercueil (2012) and Kvint (1999).[1])

First, and as a signal of the convenience of inserting elements in the course from the cultural heritage of the students, a topic on the use of dyes by ancient Mesoamerican settlers is developed. In this way it is recommended to base the discussion inside the chemistry class on the own history and environment of students. Three dyes will be analysed with its formulas and structures.

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[1] Although the term "emerging" has received several meanings, the authors have decided to use it because it is widespread, and can be interpreted as mentioned by Julien Vercueil (2012) who proposed a pragmatic definition of the "emerging economies" displaying the following characteristics:

1. Intermediate income. PPP per capita income is comprised between 10% and 75% of the average European Union income.
2. Catching-up growth during at least the last decade, it has experienced a brisk economic growth that has narrowed the income gap with advanced economies.
3. Institutional transformations and economic opening, during the same period, it has undertaken profound institutional transformations which contributed to integrate it more deeply into the world economy. Hence, emerging economies appears to be a by-product of the current globalization.

At the beginning of the 2010s, more than 50 countries, representing 60% of the world's population and 45% of its GDP, matched these criteria, among them, the BRICs (Vercueill, 2012, p. 10).

Kvint (1999) mentions that the eight largest «emerging» economies by either nominal or inflation-adjusted GDP are the BRIC countries (Brazil, Russia, India and China), as well as MINT (Mexico, Indonesia, Nigeria and Turkey).

Maya Blue, Cochineal and Tyrian Purple, emphasizing the use of colour paintings in the walls and the clothes of people since Palaeolithic age in which chemistry has had a preeminent role. As part of the STS approach for science teaching, the history of scientific development (Zeidler & Keefer, 2003) is considered in this first example. Introducing some elements of history and philosophy of chemistry is conducive towards a better understanding of scientific progress, and the nature of chemistry: "*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 [Knowledge Development in Chemistry] curriculum emphasis*" (Eilks, Rauch, Ralle, & Hofstein, 2012, p. 7).

A second example is the search for scientific-humanistic education based on the critical pedagogy movement founded by Paulo Freire, a remarkable Brazilian educator and pedagogue. He conceived the educational process as a practice of freedom, having the goal to change the context of alienation generated by oppression as outlined in *Pedagogia do Oprimido* [Pedagogy of Oppressed] (Freire, 1970). It is included the analysis of a text written by Wildson dos Santos where this author tries to construct a radical vision of a scientific-humanistic education by modifying the science and technology exclusive model by one that promotes the transformation of social inequality found in the globalized world. It includes the analysis of a text written by … modifying an exclusive model of science and technology by one ….

Two cases of inclusive practice of chemistry for secondary students are presented in the third example. They focus on social and regional problems and the promotion of environmental care from the sustainable development perspective. The topics are: chemical composition, chemistry properties, pH, and solutions. These issues allow the analysis and discussion of the omnipresence of chemistry in life and the important impact of human activity on nature. In the first case medicine and food labels are used in order to teach the presence of chemical compounds in known products, writing chemical structures, studying chemical properties, enhancing searching abilities in different sources, including the Internet, and so on. In the second case the focus is on the soil as the central topic for a particular group of students that live next to a dumping ground. This design was carried out for chemical bonding and solutions and provided new strategies for understanding the pH concept.

MEXICO: ANCIENT DYES AT MESOAMERICAN CULTURE

Aikenhead (2005b) tells us that in the "*history of humankind, people have engaged in activities we associate in some way with chemistry. But people have done so within a framework of their own culture, not within a Western science cultural framework in which the discipline of chemistry exists*" (p. 1). That is why the cultural influences on chemistry have to be found by looking at alternative cultures. We are going to do an exploration on Mayan culture to know something related with some dyes very important for cultural reasons: Maya blue, Cochineal, and

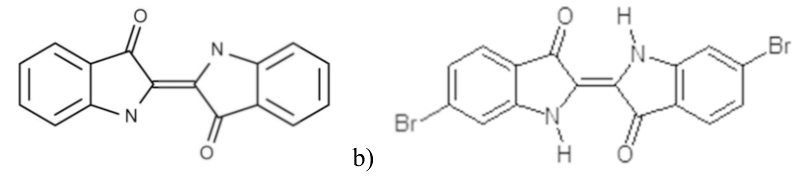
Tyrian Purple. The first one is a mixture of organic-inorganic components: indigo and palygorskite; the second is obtained from an insect ("grana cochinilla" in Spanish or "nocheztli" [blood of tuna] in Náhuatl, with the common name *Dactylopius coccus*) [woodlouse or cochineal in English], parasitic of the cactus (*Opuntia ficus-indica*), and the third one is a mucus of a snail gland. A teaching/learning sequence has been constructed on the topic and has successfully been applied in a general chemistry course at the college level, first semester.

Berke (2007) has studied the blue and purple dyes of Egyptian (the blue, with formula $CaCuSi_4O_{10}$) and Chinese (the blue with barium instead of calcium: $BaCuSi_4O_{10}$) cultures. The Egyptian and Chinese copper-based pigments have apparently been developed independently. He says, "*colour and painted objects were valued greatly in ancient times and their frequent use aggravated the lack of, mainly the rare, blue colour materials*" (p. 16).

Maya Blue

Ancient Mesoamerican dyestuffs belonged to five large botanical families: carotenoids, flavonoids, antocians, quinones, and indigoids. Maya Blue, within the family of indigoid dyes, was developed by the native cultures of Mesoamerica on a very different chemical basis than the aforementioned Egyptian and Chinese pigments. It is the name of a hybrid organic and inorganic pigment, used by the Mayan civilization to decorate pots, sculpture, codices, and panels. While its date of invention is somewhat controversial, the pigment was predominantly used within the classic period beginning about AD 500. The distinctive blue colour, as seen in the classic Maya site of Bonampak in the state of Chiapas, Mexico in Figure 1, was created using a combination of materials, including indigo (Figure 2a) and palygorskite (called «sak lu'um» or 'white earth' in the Maya language) or sepiolite. Mines for the palygorskite component of Maya Blue are located at Ticul, Yo'Sah Bab, Sacalum, and Chapab, all in the Yucatán peninsula of México.

Figure 1. A detail of room 2 of Bonampak's Temple of the Paintings. The colour between the two warriors is like a sky blue, made with Maya blue pigment. The Bonampak mural paintings completely cover the walls of three rooms in the "Templo de las Pinturas", a small building on the first terrace of Bonampak's acropolis. The human figures are portrayed about two-thirds of life size, and they tell a story related to the life of Chan Muwan, one of the last rulers of Bonampak, who married a princess from Yaxchilan, probably a descendant of Yaxchilan's ruler Itamnaaj Balam III (also known as Shield Jaguar III). According to a calendar inscription, these events took place in AD 790



a) b)

Figure 2. a) Chemical formula for indigo dye: $C_{16}H_{10}N_2O_2$. It was first obtained from indigo plant. The blue of the jeans is indigo, today obtained synthetically. b) Dibromo-indigo, the compound of Tyrian purple dye. An addition of two bromine atoms bonded makes it from a blue vegetal product to an animal one of purple colour

The striking turquoise colour of Maya Blue has survived through times, with visible colours left on stone steles after hundreds of years in the subtropical climate at sites such as Chichén Itzá (Yucatán) and Cacaxtla (Tlaxcala).

Using a series of analytical techniques, scholars have identified the content of various Maya samples. A recent study of the interior polychrome murals at Calakmul (Vázquez de Ágredos-Pascual, Domenéch-Carbó, & Domenéch-Carbó, 2011) conclusively identified a blue painted and modelled substructure dated to ~150 AD; this is the earliest example of Maya Blue to date (Figure 3).

Figure 3. An example of picture with Maya blue at Calakmul, Yucatán. The dress of the lady at the left is blue

Maya Blue requires the combination of ingredients – the indigo plant and palygorskite ore – at temperatures between 150 and 200 degrees centigrade, reached in a kiln built for that purpose. Such heat is necessary to get molecules of indigo incorporated into the white palygorskite clay forming a hydrogen-bonded organic/inorganic complex. It is incredible that such ancient people came to dominate such a technique. The process of embedding (intercalcating) indigo into the clay makes the colour stable, even under exposure to harsh climate, alkali, nitric acid, and organic solvents.

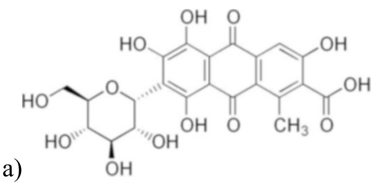
Non-Mayan eyes first saw the paintings by the beginning of the 20th century, when a local Lacandón Maya aborigine accompanied the American photographer

Giles Healey to the ruins where the last took the first photos of the paintings within the building. Many Mexican and foreign institutions organized a series of expeditions to record and photograph the murals, including the Carnegie Institution of Washington, and the Mexican Institute of Anthropology and History (INAH). From 1998, a project by Yale University directed by Mary Miller aimed to record the painting with a higher definition technology (Miller & Martin, 2005).

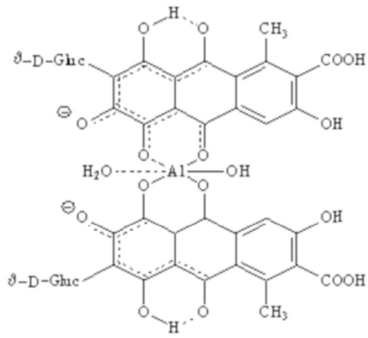
Cochineal

The cochineal (*Dactylopius coccus*) is a scale insect, from which the coloured dye carmine is derived. As a primarily parasite, this insect lives on cacti in the genus *Opuntia*, feeding on plant moisture and nutrients. The insect produces carminic acid that deters predation by other insects.

The Aztec and Maya peoples of Central and North America used cochineal dye. Eleven cities conquered by Montezuma in the 15th century paid a yearly tribute of 2000 decorated cotton blankets and 40 bags of cochineal dye each. During the colonial period the production of cochineal "grana cochinilla" grew rapidly. Produced almost exclusively in Oaxaca by indigenous producers, cochineal became Mexico's second most valued export after silver during the colony. In Figure 4a, the formula of the carminic acid is shown, and in Figure 4b the aluminium chelate of the carminic acid, that corresponds to the red dye.



a)



b)

Figure 4. a) Formula of carminic acid: $C_{22}H_{20}O_{13}$. The cycle to the left is glucose. To the right of it a carboxilic acid derivative of anthracene (3,5,6,8-tetrahydroxy-1-methyl-9,10-dioxoanthracenecarboxylic acid). b) This is the aluminium chelate of the carminic acid, with the stoichiometry 1:2. This aluminium compound is the red dye used in Mexico since the pre-Columbian age. There are pioneer quotes on the use of Cochineal, as in the illustrations of Antonio Alzate (1977) in which he showed an "Indian Collecting Cochineal with a Deer Tail" or in the old engraving painted by Aimé Bonpland (1773-1858), the French botanist that came with Humboldt on his trip to America

Tyrian Purple

Tyrian Purple is the deep purple pigment used for elite clothing beginning in the Roman period and illuminated manuscripts through the Middle Ages. The dye was greatly prized in antiquity because the colour did not easily fade, but instead became brighter with weathering and sunlight.

Variously known as Royal purple, Tyrian purple, Byzantine Purple, purple of the ancients, this ancient dyestuff, mentioned in texts as early as 1570 BC, was produced from the mucus of the hypobranchial gland of various species of marine molluscs, notably *Murex Brandaris* and *Nucella Lapillus*. The ancient Phoenicians possibly first used this dye. Although originating in Tyre (hence the name), large-scale chemical industry spread throughout the world. With the decline of the Roman Empire, the use of the dye also declined and massive production ceased with the fall of Constantinople in 1453. It has been replaced by other cheaper dyes like lichen purple and madder.

It is interesting that during the pre-Hispanic era, the purple dye was extracted also from certain kinds of marine snails in the Mayan area, mainly the whelk of *Purpura Patula Pansa* (Figure 5). The major component of the dye is 6,6'-dibromoindigo (see Figure 2b).

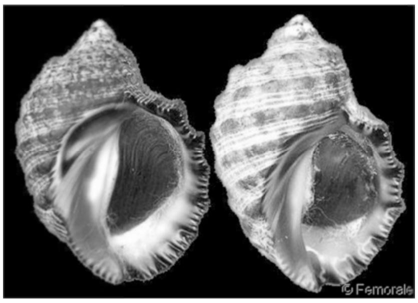


Figure 5. The snail Purpura Patula Pansa

How the mollusc makes dibromoindigo is shown in the teaching/learning sequence elaborated, through a set of three reactions in which the presence of oxygen and light promotes the final occurrence of this compound obtained from the colourless indoxyl sulfate. It is said that Phoenicians discovered it when a dog bit a snail, which made the chemical transformation thanks to the presence of air and sunlight.

The main result of applying the teaching/learning sequence to the general chemistry students in Mexico was innovative, because pupils included role-playing and debates on the topic of the conservation of pictures made with those dyestuffs. They were acting divided in several groups: Mayan natives in pro of the dissemination of artistic information; Mayan natives in contra; people of the major's office of Calakmul; foreigners; workers in the National Museum of Anthropology.

BRAZIL: A JUXTAPOSITION OF HUMANISTIC AND SCIENTIFIC EDUCATION

Background

Since the 1970s in Brazil some science educators have shown a concern in incorporating themes in the curriculum of scientific disciplines that involve relationships between science and society (Santos, 2008). Nonetheless, the first curricular projects incorporating STS ideas in the science teaching began to appear after 1990. As in other similar cases about transferring of ideas and debates around the curriculum, STS ideas came to Brazil from countries like United States and England and, slowly, spread through the community of science educators. The great and fast growth of research and post-graduation in science education in Brazil after 2000 contributed to the STS curricular movement, which then acquired more local colour and, at same time, developed a critical view on this movement.

In 1998, two years after the edict of the last National Law of Education that regulates Brazilian education, the government proclaimed the National Curricular Guideline to secondary schools. In this document it is possible to note the influence of ideas originated in the STS movement as, for example, the development of a socio historic view of scientific enterprises and their relationships with social changes, as well as an understanding of relationships between science and technology, and the impact and application of technology in everyday life and in problem solving. Despite incorporating such principles in the Brazilian curricular orientations, the teaching of chemistry continued with old trends of reforms from 1950s and 1960s, of a curriculum centred in the structure of the academic discipline. Thereby STS composes, with many others, an alternative movement to the traditional curriculum, which constitutes a strongly rooted model in the landscape of Brazilian science teaching.

The new Freirean proposal

One of the most interesting and original proposals arisen from Brazil is one that juxtaposes humanistic and scientific education, as found in the STS movement, with a perspective based on ideas of Paulo Freire, characterized by a radical view of humanistic-scientific education. His author, Wildson dos Santos, considers that, beyond the aim to prepare citizens to a technological society, it is necessary to get a clear view of science education with a socio-political function, that enables to question and to change the ideological model which tends to keep the *status quo* of production of scientific and technological knowledge. The critical pedagogy of Paulo Freire, according to Santos, would allow the construction of a radical view of a humanistic-scientific education, trying to change the rational and excluding understanding of science and technology towards one which promotes changing social inequality of the globalized world (Santos, 2009).

To Santos, the concept of Paulo Freire's pedagogy shares with the STS movement a humanist view, which searches to develop human values among students, as in the *Bildung* paradigm. In his pedagogy, Freire privileged the most oppressed people of Brazilian society (see the chapter by Sjöström et al. in this book), and conceived the educational process as a practice of freedom which has as its main goal changing the alienated context generated by the oppression in which this people live (Santos, 2008). Santos proposed a new way of educational practice, which instead of reproducing the world status intends to change it. Interpreting science education in a Freirean perspective, Santos asserts that traditional science education brings the dominant values of technology which places human interests under those purely associated to the market in which we are all inserted, considering such education as oppressive (Santos, 2008).

Santos' perspective

A STS curriculum in a Freirean perspective would have as a focus the dominating process that the current system of technological production imposes us, overlapping cultural values and offering risk to human life (Santos & Mortimer, 2002). In relation to Brazil and other emerging countries, this process is socially excluding, because only a small part of the population enjoys its benefits, while the greater part remains on the margins (Santos, 2008). Santos alleges that a Freirean perspective in STS education is not against the use of technology, but an education in which students can think critically about their situation in the world in face of all challenges posed by science and technology (p. 122). It must allow all students to understand the technological world in which they are inserted and all contradictions that involve the presence of science and technology in society, in order to transform it based in human values. The broadening of the STS approach with a Freirean perspective, according to Santos, means to rescue the political agenda of this movement, because it aims to prepare students to act politically in society (Santos, 2009).

One of the instances with which Santos illustrates the adoption of a Freirean perspective in a STS approach to the chemistry curriculum is through the theme "waste". In addition to identifying the chemical products present in waste, or the separation methods adopted in a recycling plant, it is also important to discuss why there are people in our societies that live in landfills: "*It is necessary to discuss not only the benefits of modern technology, but why only one third of the global population has access to technology whereas the other two thirds do not have the most basic, minimally humane living conditions*" (Santos, 2009, p. 370). The discussion of aspects like these allows focusing the context of domination that characterizes our modern scientific and technological society.

Printed materials

Santos and co-workers developed in Brazil a series of materials for the chemistry teaching in the secondary schools through the Chemistry and Society Teaching Project, which resulted in the textbook *Química e Sociedade* [Chemistry and Society] (Mól et al., 1998, 2000, 2003). In this textbook, chemistry concepts are articulated by means of a socio-scientific approach in a session called "Theme in

Focus" (Santos, 2009). These themes are an adaptation of the Freirean perspective on the literacy of youths and adults belonging to poor communities to chemistry teaching. Based on this pedagogy, the authors approach the contexts of science and technology and relate them to the social issues of the world where we live. Themes can both precede chemical concepts or follow on from them, and they are chosen in order to be socially relevant to the students. Themes should also create opportunities for the engagement of students through a dialogical process in a debate that will lead them to socio-political decision-making.

The organization of activities contextualized from the themes in Santos et al. (2012) is what sets the book *Chemistry and Society* away from other books for secondary schools, where technological features are addressed in an illustrative and complemented manner to the content of chemistry. There is no *a priori* separation between the "theme in focus" and the chemistry content as always seeking greater interaction between their approaches, and socio-scientific and technological aspects are discussed throughout the book (Santos et al., 2009). Thus, each unit has a societal relevant issue, which permeates the entire discussion of the unit, seeking to critically discuss issues from the technical rationality to environmental exploration and production of scientific and technological knowledge. The generator theme that introduces social issues seeks to establish, from the outset, relations with the chemical concepts that are explored into the book. According to the authors, socio-scientific aspects constitute the curriculum as specific contents of chemistry, and should be treated in an articulated manner and highlight the role of the citizen in decision making about the fate of technological development (Santos et al., 2012). This mixture of individual, societal, and vocational realms is what makes this focus relevant.

The curriculum design chosen for the book *Chemistry and Society* seeks to adjust to that developed in high school, "*characterized by conventional school practices*" (Santos et al., 2012, p. 70). Thus, the proposed thematic approach is incorporated to the classical curriculum model and therefore its design can be considered hybrid. Each unit combines a topic of the content of chemistry with a theme of technological nature linked to chemistry and to the everyday life of students (Santos et al., 2009). Teachers, however, are encouraged to re-contextualize the texts of the "Themes in Focus" in order to bring them closer to the daily lives of their students.

Textbook contents

The book *Chemistry and Society* became a collection in three volumes and it was recently included in the National Textbook Program, which makes it one of the five chemistry textbook collections of free distribution among students of public schools in the whole nation to be chosen by chemistry teachers. In volume 1, for example, the second unit is dedicated to the study of gases, atomic models and air pollution. In its first chapter, the section Theme in Focus presents an article about air pollution and global warming. The following sections discuss the specific contents: 1 – Measurements, models and phenomena; 2 – Quantities of solid state;

3 – Properties of gases; 4 – Laws of gases; 5 – Kinetic theory. The next chapter begins with an essay on the ozone layer and solar radiation, approaching afterwards to atomic models and theories, from Dalton to the quantum model. A second text *Química cidadã* [Chemistry citizen], discusses the carbon market and sustainable attitudes (Santos & Mól, 2010, Figure 6).

Unfortunately, most Brazilian chemistry teachers seem to prefer the more conventional books, in which the curriculum develops focused on specific contents of chemistry. In our experience, we realize that chemistry teachers are interested in making education more relevant to their students and they understand the importance of this in the articulation and contextualization of content with daily life or societal issues. However, the introduction of innovations in teaching is more time consuming for Brazilian teachers, and time is quite scarce for most of them. Amid the pressures and demands from examinations and national assessments, conventional books seem to offer security and greater confidence that the extensive chemistry curriculum can be satisfied.

Figure 6. Cover of the text coordinated by Santos and Mól (2006)

MEANINGFUL CHEMISTRY TEACHING AT SECONDARY ARGENTINEAN SCHOOLS

The third example has to do with two experiences developed in five high schools of the Provincia de Buenos Aires, Argentina. Both experiences were simultaneously put into practice employing the collaborative work methodology in the framework of the "Science by and for Everyone" Program (Lorenzo, 2006).

Teaching chemistry by and for everyone

Everywhere, but mainly in emerging countries, science and technology teaching must not only include scientific concepts and theories of science but *about* science and technology in order to understand their function and nature. It is to say, science teaching implies knowledge and meta-knowledge (nature of science) of a particular discipline to reach societal relevant learning, including ethics and democratic values (Vázquez-Alonso & Manassero-Mas, 2012). Science-Technology-Society (STS) offers an excellent milestone to organize meaningful chemistry teaching for secondary students.

Nowadays, it is clear that chemistry teaching and learning requires holistic strategies beyond the classical and transmissive way of teaching. It is necessary to deeply impact in scientific literacy for all students, within an inclusive framework in order to guarantee learning opportunities for all human beings. From this point of view, chemistry teaching must promote an integration of the scientific culture, its methods, objectives, challenges, and history.

In order to improve chemistry teaching, there is currently a growing production of strategies, recommendations and tips for teachers training from diverse perspectives of developing pedagogical chemistry knowledge (Bucat, 2004; Bond-Robinson, 2005; Garritz & Trinidad, 2005; Garritz, 2013). To this respect the recent book edited by Eilks and Hofstein (2013) is a very significant example.

The pedagogical proposal which is discussed blow has been developed in the framework of the "Science by and for Everyone" (CET, stands for the Spanish name of the Program: *Ciencia Entre Todos*) program by the School of Pharmacy and Biochemistry in the University of Buenos Aires. This program is focused on quality improvement of science teaching and learning at different educational levels, extending to the scientific literacy for the whole educational community, as proposed by Hodson (2008). Therefore, it tries to answer a series of questions of special significance for the secondary school level and the first years of university education. It also addresses the updating and training of teachers, and the available advise for the resolution of specific problems in specific contexts.

In this sense, the proposal included two experiences, both them were simultaneously put into practice in five different secondary schools of the Provincia de Buenos Aires, Argentina. A particular methodology has been specially designed for these activities, names as entangled-methodology (Lorenzo & Rossi, 2008). It consists on collaborative work (Balocchi et al., 2005) among diverse schools, teachers and students where each one acts as a source of problems and solutions, questions and answers. They included the exchange of information and materials (samples, particular objects, photographs) by using different ways of communication such as post-mail, e-mail, meetings, and phone. A constructivist point of view was followed, as recommended by Driver, Asoko, Leach, Mortimer, and Scott (1994). The entangled-methodology has been useful for students' thinking, analysing and evaluating their own problems, in order to explore new answers for those problems. The network always pointed to the improvement of the educative quality and academic excellence.

Rationale of the pedagogical activities design

If educators are to effectively educate learners in knowledge, skills, and values it will be needed to create more sustainable places and communities, a transition from traditional teaching models to transformative learning processes should be encoiuraged (Burns, 2011).

To this purpose it is imperative to take into account prior knowledge of students, their actual experiences and their social environment so as to promote conceptual change (Posner, Strike, Hewson, & Gertzog, 1982) and learning. Hence, pedagogical proposals must support this process by offering opportunities of construction of meanings. In this way problem-based learning (PBL) gives a good model to design some open practical work. This learning model includes the development of critical thinking, communication skills, the ability to tackle unfamiliar and/or open-ended problems, and so on. In addition, PBL gives students opportunities for being autonomous as well as collaborative when handling problems (De Jong, 2011).

According to these desired goals, different stages have been included in the lessons presentation:

1. Initial activities: Student engagement begins with a provocative question related to their lives. The teacher comes up with the trigger question and guides them to put ideas together and to pose the problem to investigate.
2. In the second step fieldwork and/or experimental work are implemented depending on the topic. The tasks include: sample determination, experimental designs, data collection, visualization, analysis and comparison of data and results. Different ways or formats for presentation of data can be employed: tables, graphics, text, and/or pictures. In this stage the teacher scaffolds to the students by answering their question and asking new ones in order to progress in problem solving.
3. As problem solving progresses, students discuss preliminary results in order to finally arrive to the conclusions and implications elaboration in the third stage. Then, they can read and understand articles in the popular press and engage in social conversation about the validity of the conclusions; identify scientific issues underlying national and local decisions, and express ideas that are scientifically and technically informed;
4. To complete the activity in a similar way to scientific work, it is very important not to forget the report writing and a poster session discussion in the last stage where different angles of subject matter become visible. It allows the promotion of scientific literacy exposing and engaging students in activities that involve problem solving and critical thinking (McGhie-Richmond, Underwood, & Jordan, 2007).

Two examples of real problems for students

Close and relevant problems arouse major attention in students. Both of the examples presented here were thought as inclusive practices of chemistry for secondary students. They focus on regional social problems and on the promotion of environmental care from the sustainable development perspective. The selected topics were chemistry composition and chemical properties, pH, and solutions. These issues provide the analysis and discussion of the omnipresence of chemistry in life and the important impact of human activity on nature.

The activities combine a STS perspective with problem-based learning and consider the importance of experimental work, first-hand experience, observation and manipulation (Hofstein, 2004, Hofstein & Mamlok-Naaman, 2007, Nakhleh, Polles, & Malina, 2002). Two relevant examples of everyday life have been chosen: a) medicine and food labels; and b) the unseen soil under our feet.

a) Medicine and food labels. In the first case medicine and food labels were used in order to teach the presence of chemical compounds in known products, by writing chemical structures, studying chemical properties, enhancing searching abilities in different sources, including the Internet, and so on. Food and medicine labels contain a lot of diverse (and useful) information, not only related with chemical inorganic and organic compounds, but also with nutritional recommendations, conservation indications and shelf life. Using scientific and teaching creativity together, labels provide a huge range of topics: product name, net weight, ingredients (saturated and trans fats, artificial sweeteners, food dyes, additives, preservatives), composition, nutrition facts, calories intake, date of manufacture, deadline, storage mode, method of use, target, warnings, batch, manufacturer data, origin, food containers (polymers, cans), manufacturing processes, among others. In Figure 7 two typical examples are shown. Because of their huge possibilities they also promote social attitudes, conscientious purchase and consumption, and health issues.

<table>
<tr><th>Milk label</th><th>Dental cleaner ingredients</th></tr>
<tr><td>
</td><td>Sodium Bicarbonate,
Citric Acid
Potassium Carbonate
Sodium Carbonate,
Sodium Carbonate Peroxide
Sodium Benzoate
PEG-180,
Sodium Lauryl Sulfoacetate
Subtilisin
PVP/VA Copolymer
CI 42090, CI 73015</td></tr>
</table>

Figure 7. Two typical examples of food and medicine labels

b) Soil near a dumping ground. Soil is what there is under our feet, our roads, and our buildings. Because soil is everywhere it is difficult to think about it. Therefore it becomes an excellent topic for high school chemistry classes. It is not only our place in the world, but the main resource of food for animals and human beings and materials for industrial activities. Soil is a mixture of minerals, organic matter, gases, liquids and innumerable organisms, and supports life on earth. From a chemical point of view, soil is a complex and dynamic system and its properties are related with the presence/absence of certain dissolved ions and with its pH.

The soil is also intensely affected by human activities. It is exposed to several pollution sources either in rural or in urban zones, like dirty water, garbage, toxic industrial wastes, plastics, poisons, or metals. All these features produce contamination of soil and subterranean water; and also promote the growing of non-desirable organisms (Ballenilla, 2005). In this way, the soil is a key topic to teach and to learn chemistry concepts while promoting green attitudes.

Our second experience was focused on the soil of the five different regions where the schools were located: three schools were urban/suburban, one was rural (farming zone) and the other was located in a very poor neighbourhood next to a dumping ground, where those students and their parents live and work (Moro, Tíntori Ferreira, & Lorenzo, 2010). So, these variety of places, yield a heterogeneous panorama of landscapes and therefore soils characteristics that favoured a significant activity for chemistry teaching.

Some common difficulties around the concept of solutions exist. The students are confused by the nature of a solution with the process of mixing, while others are not capable to distinguish between solution and pure substance (Nappa, Insausti, & Sigüenza, 2005, Prieto, Blanco, & González, 2000). So, the pedagogical proposal was a good opportunity to work on the topic 'solution' and related contents.

The lesson had an open problem-solving experiments structure. It began with a question from the teacher about a real problem: What is the soil where we live on like? Is it different from the soil of other communities? How did pollutants (and other substances) appear in the soil? Can they be dissolved in water? The questions should help students to make connections and develop their own hypotheses, develop their plan of investigation, and the way of collecting and analysing data. Besides, they had to write their own report with results, discussion, and conclusions. Finally, they had to present their work in a poster session. This design was carried out for acid/bases and solutions and provided new strategies for understanding pH. Chemical compounds were related with the forming agents of the ground and its pollutant.

This experience was enacted as an entangled activity (Lorenzo & Rossi, 2008). Pictures, information, reports and soil matter were exchanged among students from different schools using postal mail. Then the activity was completed with the comparison and analysis of different soils samples of each participating school.

Additional comments about actual results on field

The main purpose of these activities proposal was to help students to understand the world where they live, to encourage them to seek the origin or the reason of some particular phenomena in their surroundings. At the same time a narrow connection between science classes and personal experiences, feelings and needs of students were fostered (Pozo & Gómez Crespo, 2002).

From this involvement derived from "hands on" and comprehension by doing science, students learned about the environmental impact of human activities, the experiences of other students, the habits of different people, and they related them to science school contents. We believe that they promoted critical thinking and decision making on students and in the whole school community.

The outcomes showed not only a good learning of chemical concepts (quizzes scoring) but also good achieved competences by students like:

- Team working, seeking abilities
- Enthusiasm and good organization in field working
- The respect of security laboratory norms for safety
- The discussion and defence of their ideas in a framework of permanent respect, as well as the learning to accept differences and different situations and views provided by the work of the other schools.

In search of the expert pedagogue, David Berliner made clear that teaching for understanding is based on a genuine scholarship of practice. That is why teacher's actions were related to many complicated items: knowledge and beliefs, content and pedagogy, teaching and learning, in such a way that teaching practice is complex and interwoven (Loughran, Mulhall, & Berry, 2004, 2012). That is also an important explanation of what the authors have categorized as the methodology or the activities 'entangled' in this third example of the chapter.

CONCLUSION

Chemistry teaching must not be frozen in time repeating the same practices over and over. The school must not be seen as an isolated cell. Instead it is necessary to consider it as important part of the community and the society to promote inclusive and solidarity values and responsibility. In those kinds of school settings, students are capable to spread off their creativity, to find solution to real problems and to become better citizens. In our three examples the relevance of them appears through attention to the idea of consequences, as explained by Stuckey et al. (2013). Consequences encompass real impacts in socio-economical means on the students' physical and material life (today and in the future).

From this point of view, STS chemistry teaching provides learners with opportunities to think critically about dominant paradigms, practices and power relationships and consider complex ecological and social issues from diverse perspectives. It also enhances learners' civic responsibility and intentions to work toward sustainability through active participation and experience. To learn in context (Gilbert, 2006) enables learners to enlarge their understanding of and to connect with the geographical place and the community in which they live. This chapter has revised some examples of chemistry education via socio-scientific issues employed in some emerging countries of North and South America.

The authors want to stress that those issues cover all kind of students in those emerging countries, with a 'Science by and for All' focus on both, local and international aspects. The awareness must be also emphasised of a desired vision of science in democratic society, in terms of increased number of "recruits", greater support for scientific research, and more realistic public expectations toward science. Notwithstanding the massive research endeavours of the pharmaceutical, electronic, armaments and aircraft industries, a great deal of the financial support for fundamental scientific research derives from public funds, so it is important to keep citizens informed about what scientists do and how it is done.

Finally, teachers have the challenge to transform everyday problems into learning situations promoting students collaborative problem-based learning, informed decision-making, inquiry, argumentation, debate, experimentation, critical thinking, and communication skills, moving them to more informed views of the nature of science.

Many of the recommendations given in this chapter are applicable not only in emerging countries, but throughout the world. These proposals, which were actually enacted in chemistry classes, showed us that to combine STS with open problems, a different teaching/learning philosophy, and anthropological examples are a good road to follow for the future of chemistry education.

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14. UNDERSTANDING THE CHANGE TOWARD A GREENER CHEMISTRY BY THOSE WHO DO CHEMISTRY AND THOSE WHO TEACH CHEMISTRY

Genesis of the Green Chemistry movement can be traced back to a change in U.S. national policy that occurred slightly less than 25 years ago to focus on preventing pollution at its source rather than trying to treat it once it was released into the environment. The chemical industry understands the importance of a greener approach because it simultaneously has economic, social and environmental benefits; a combination that has been termed the triple bottom line. Advocates of a green chemistry approach to teaching chemistry recognize that it also has the advantage of motivating students to more actively participate in our courses because it connects chemistry to the world in which they live and the challenges society faces. This chapter will examine the forces that led to the creation of the Green Chemistry movement, provide examples of the commitment to green chemistry among practicing chemists in the chemical industry, describe efforts to disseminate innovative approaches to teaching chemistry based on the principles of green chemistry and engineering, and summarize efforts by groups such as the American Chemical Society and the Royal Society of Chemistry to foster the implementation of green chemistry ideas.

INTRODUCTION

The primary constraining factors when the author first started to think about building a laboratory program to accompany a two-semester general chemistry course for science and engineering majors that enrolled more than 3500 students each semester are easy to imagine. The experiments had to be compatible with the equipment available in each of the thousands of laboratory drawers to which students were assigned. The cost of purchasing chemicals was an important constraint because literally thousands of students were doing the same lab experiment each week. Safety, of course, was another important factor influencing the design of new experiments. But, the author is sorry to say, waste products were typically flushed down the sink adjacent to each student's lab bench.

Now try to imagine the priority of the constraining forces if he was trying to do the same thing today. It shouldn't be surprising that the cost of disposal of potential waste products generated in these experiments has become a more important factor than the cost of purchasing the chemicals in the first place.

I. Eilks & A. Hofstein (Eds.), Relevant Chemistry Education – From Theory to Practice, 263–284.

Let's now leave the context of an academic laboratory to consider the industrial process Pfizer first used to prepare the drug sildenafil citrate (Viagra™). At one time, it took 1350 liters of solvent to produce one kilogram of this drug. In order to control costs, Pfizer worked to decrease the volume of solvent to the point that it now takes only 6 liters of solvent per kilogram of product (Nottingham Science, 2014). From an industrial perspective, this is an example of a phenomenon known as the "triple bottom line" because it simultaneously has economic, social and environmental benefits.

The two fundamentally different contexts for doing chemistry described in this introduction have something in common. They both reflect an ever-increasing commitment to the concept of green chemistry.

The US Environmental Protection Agency defines green chemistry as "*the design of chemical products and processes that reduce or eliminate the generation of hazardous substances*" (EPA, 2014a). Like so many others, the EPA couples the concept of "green chemistry" to the idea of generating a "*sustainable and healthy economy*." They also emphasize the difference between green chemistry and cleaning up pollution by noting that "*Green chemistry reduces pollution at its source by minimizing or eliminating the hazards of chemical feedstocks, reagents, solvents, and products.*"

HISTORY OF THE GREEN CHEMISTRY MOVEMENT

The Green Chemistry movement can be traced back to the Pollution Prevention Act of 1990, which established a national policy in the U.S. that focused on preventing pollution at its source rather than treating pollutants once they were formed. Section 6602(b) of the Pollution Prevention Act set forth the following policy for the United States (EPA, 2014b):

- Pollution should be prevented or reduced at the source whenever feasible,
- Pollution that cannot be prevented should be recycled in an environmentally safe manner whenever feasible,
- Pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible, and
- Disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner.

When the Pollution Prevention Act of 1990 was signed into law, Paul Anastas was the head of the Industrial Chemistry Branch at the EPA. In 1991, Anastas invented the term *green chemistry* to describe a different way of thinking about how chemistry and chemical engineering are done. As noted on the American Chemical Society website (ACS, n.d., a):

> It's important to note that the scope of … green chemistry and engineering principles go beyond concerns over hazards from chemical toxicity and include energy conservation, waste reduction, and life cycle considerations such as the use of more sustainable or renewable feedstocks, and designing for end of life or the final disposition of the product.

When asked: How did you come up with the name "green chemistry," Anastas responded: "*they think I'm joking when I say, well, green is the color of nature but in the United States green is also the colour of our money. It's always been about how you meet your environmental and economic goals simultaneously*" (Sanderson, 2011).

A major step forward in the Green Chemistry movement occurred in 1995, when President Clinton created the Presidential Green Chemistry Challenge Awards. These awards do more than give credit where it is due; they serve as both models for others to follow and a way of tracking progress. For a technology to be considered an example of green chemistry, it must be more environmentally benign than existing alternatives, more economically viable than existing alternatives, and functionally equivalent to or capable of outperforming existing alternatives (Warner Babcock, 2014). According to the Warner-Babcock Institute for Green Chemistry website, only 10% of current technologies are "*environmentally benign, while another 25% could be made benign relatively easily*." This means that there is a great deal of room (65%) for further innovation.

John Warner, of Warner-Babcock is recognized as a co-founder of the Green Chemistry movement. Warner worked with Anastas to create the Presidential Green Chemistry Challenge Awards and served as co-author with Anastas of the seminal textbook in the field: *Green Chemistry: Theory and Practice* (Anastas & Warner, 1998).

GUIDING PRINCIPLES OF GREEN CHEMISTRY AND ENGINEERING

In *Green Chemistry: Theory and Practice*, Anastas and Warner set the basis of a movement that others could follow by developing a set of 12 guiding principles for green chemistry. The original wording of these guiding principles can be found on various websites (see, for example, CGCGE-Yale, n.d.). But the language with which they are described has been made a little less technical in recent years. As described on the EPA website that defines the basics of green chemistry, for example, they are:

12 Principles of Green Chemistry

1. Prevent waste
   Design chemical syntheses to prevent waste. Leave no waste to treat or clean up.
2. Maximize atom economy
   Design syntheses so that the final product contains the maximum proportion of the starting materials. Waste few or no atoms.
3. Design less hazardous chemical syntheses
   Design syntheses to use and generate substances with little or no toxicity to either humans or the environment.
4. Design safer chemicals and products
   Design chemical products that are fully effective yet have little or no toxicity.

5. Use safer solvents and reaction conditions
   Avoid using solvents, separation agents, or other auxiliary chemicals. If you must use these chemicals, use safer ones.
6. Increase energy efficiency
   Run chemical reactions at room temperature and pressure whenever possible.
7. Use renewable feedstocks
   Use starting materials (also known as feedstocks) that are renewable rather than depletable. The source of renewable feedstocks is often agricultural products or the wastes of other processes; the source of depletable feedstocks is often fossil fuels (petroleum, natural gas, or coal) or mining operations.
8. Avoid chemical derivatives
   Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.
9. Use catalysts, not stoichiometric reagents
   Minimize waste by using catalytic reactions. Catalysts are effective in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and carry out a reaction only once.
10. Design chemicals and products to degrade after use
    Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.
11. Analyze in real time to prevent pollution
    Include in-process, real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts.
12. Minimize the potential for accidents
    Design chemicals and their physical forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.

These principles can be divided into two broad categories: (1) reducing risk and (2) minimizing the environmental footprint. If asked to do so, the author could discuss in great detail the implications of many of these guiding principles in terms of providing new ways to think about the process of "doing chemistry." But, there is one point that deserves particular attention, the focus on safety. As Anastas in an interview noted (Sanderson, 2011):

> When I was getting my PhD in chemistry I was expected to translate technical articles from French and German to English … But I can tell you I have never, ever, had to translate an article … in all of my working life. And yet there was never any requirement that I needed to know the first thing about toxicity or the hazards of the tools of my trade – the chemicals. I never had to take a test that required me to understand the consequences of the molecules that I was introducing into the Universe or the ones that I was using on a daily basis. There's an absurdity there that needs to be addressed.

Anastas and Zimmerman (2003) went on to define *green engineering* as "*the development and commercialization of industrial processes that are economically* *feasible and reduce the risk to human health and the environment.*" The guiding principles for green chemical engineering were defined as follows (Anastas & Zimmerman, 2003):

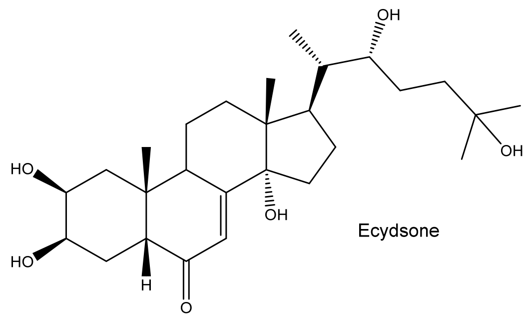
12 Principles of Green Engineering

1. Inherent rather than circumstantial
   Designers need to strive to ensure that all materials and energy inputs and outputs are as inherently nonhazardous as possible.
2. Prevention instead of treatment
   It is better to prevent waste than to treat or clean up waste after it is formed.
3. Design for separation
   Separation and purification operations should be designed to minimize energy consumption and materials use.
4. Maximize efficiency
   Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
5. Output-pulled versus input-pushed
   Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials.
6. Conserve complexity
   Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
7. Durability rather than immortality
   Targeted durability, not immortality, should be a design goal.
8. Meet need, minimize excess
   Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw.
9. Minimize material diversity
   Material diversity in multicomponent products should be minimized to promote disassembly and value retention.
10. Integrate material and energy flows
    Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.
11. Design for commercial "afterlife"
    Products, processes, and systems should be designed for performance in a commercial "afterlife."
12. Renewable rather than depleting
    Material and energy inputs should be renewable rather than depleting.

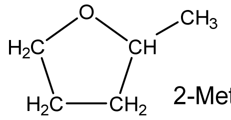
GREEN CHEMISTRY IN INDUSTRY

Case studies from the chemical industry that provide useful examples for helping students appreciate the impact of the green chemistry perspective can readily be found on the Internet. Consider, for example, the implications of the concept of "atom economy" on the synthesis of the drug ibuprofen. As industrial chemists readily admit, the first priority with the synthesis of a new compound is being able to "get it out the door." In the 1960s, that resulted in the use of a six-step synthesis of ibuprofen that had an atom economy of roughly 40%, which means that more than half of the starting materials ended up in unwanted side-products. The production of 30 million pounds of ibuprofen per year was therefore accompanied by the generation of 45 million pounds of waste. In the 1990s, BHC developed a three-step synthesis with an atom economy of as much as 99 percent, thereby allowing the company to produce more of the desired product, in less time, with less energy, and with significantly less impact on the environment. Ibuprofen provides just one of many examples that help us understand why the pharmaceutical industry has been recognized as a particularly successful example of the application of the green chemistry philosophy.

Let's now look at another example of the green chemistry philosophy, this time concentrating on the idea of designing safer chemicals and products. The 50th anniversary of the publication of Rachel Carson's *Silent Spring* (1962) was recently celebrated. Carlson's book focused attention on the negative effects of the use of DDT, a product whose positive effects included saving thousands of lives during World War II by killing disease-carrying insects. A step toward safer insecticides involved the creation of organophosphates that degrade in the environment, but these compounds are also toxic to beneficial insects. So the next step forward has involved the creation of insecticides that target specific organisms, such as *ecdysone* that inhibits insects' ability to shed their exoskeleton, i.e., to "molt," and are therefore more species specific.



The commitment of the chemical industry to green chemistry can be seen by noting that many companies provide a website dedicated to this topic. Consider the Aldrich Chemical company, for example, whose website uses the heading: "Green Chemistry: Supporting the Advancement of Chemistry through Sound Environmental, Social and Fiscal Responsibilities" (Aldrich, 2007). The first example on the Aldrich website is coincidentally the first example the author learned about when he attended one of the annual Green Chemistry and Engineering International Conferences (ACS, n.d., b): 2-Methyltetrahydrofuran.



2-Methyltetrahydrofuran

What makes this solvent "green"? First, it is obtained from renewable resources such as corncobs or the fibrous material that remains after sugarcane or sorghum stalks are crushed. It is also safer than the parent compound (THF) because it is less likely to form peroxides. It is both a polar solvent and an aprotic solvent, so Grignard reagents are more soluble in 2-MTHF than in THF. It is much easier to "dry" this solvent by removing water. Because it has only a limited solubility in water, it is much easier to separate and recover, thereby reducing the waste stream. Finally, it has a low heat of vaporization, which means that less energy is consumed during distillation and recovery.

GREEN CHEMISTRY IN THE CLASSROOM

Joining the Green Chemistry movement is not difficult because, in essence, it is just a new way of thinking about chemistry and chemical processes. Regardless of whether one is an industrial chemist worrying about how to make several million pounds of a new drug or an instructor thinking about new ways of overcoming the difficulties associated with the teaching and learning of chemistry, green chemistry does not change the facts or principles of chemistry. It just asks us to bring a new dimension into our thought process, in which chemistry is actively integrated into the world around us. A dimension in which:

1. A priority is placed on minimizing potentially negative effects on the environment,
2. Where both practicing chemists and students taking chemistry for the first (and perhaps last) time are actively involved in thinking about safe practice,
3. Where minimizing waste and maximizing atom-economy become more important concepts than the traditional driving factor: "percent yield," and
4. Where the notion of limited resources is understood and resources that are used are renewable.

The Green Chemistry movement reminds us that chemists often forget to do what they insist their students learn how to do: Balancing the equations used to represent chemical reactions so that attention is focused on not just the starting materials and target of the reaction, but the waste generated in the course of the reaction.

The author maintains that examples of green chemistry should be incorporated into every chemistry course, at any level; from the introduction to chemistry taught in the K-12 classroom through the last course graduate students take to earn a Ph.D. in the chemical sciences. A clear understanding of the green chemistry philosophy is essential for the handful of students from the general population who will go on to pursue careers in the chemical enterprise. For the vast majority of students who will not do this, green chemistry examples can provide a basis for connecting the concepts and facts we ask them to learn in the introductory course to concrete examples that are likely to be more "relevant" than the traditional exercises that have dominated our courses for so many years.

THE UNIVERSITY OF OREGON GREEN CHEMISTRY PROGRAM

For years, the author has distinguished between innovation and change within the area of curriculum reform. He argues that innovation occurs when one or more individuals find a creative solution to a local problem; change occurs when others adopt either the philosophy or content of the new approach and adapt it to fit their needs. As an example of these phenomena, consider the green chemistry program at the University of Oregon. It began in 1997, when a group of faculty recognized the existence of limits on both the infrastructure and human resources available for teaching organic chemistry. Having read about the fledgling Green Chemistry movement – and having adopted the values and beliefs it advocated – this group tried to apply green chemistry to a revision of the curriculum that would overcome the limitations on resources they faced. Working with a group of graduate students, Doxsee and Hutchinson (2004) developed a laboratory manual that introduced students to the tools and strategies of green chemistry and then outlined experiments that could be used to investigate the concepts and techniques of organic chemistry within the context of a greener laboratory environment.

The University of Oregon program gained recognition as a source of information – and, at times, inspiration – for curricular reform in chemistry by running a series of annual Green Chemistry in Education Workshops that have hosted literally hundreds of college- and university-level educators, and they have recently started offering webinars on topics such as *Catalyzing sustainable innovation* and *Green chemistry education: Not just for chemists anymore* (University of Oregon, 2014).

Because of a deep-seated commitment to dissemination, the green program at the University of Oregon has repeatedly published details of individual experiments they have developed and references to these publications are archived on one of their websites (HutchLab, 2011). They have also archived for general use the results of symposia on *Curricular Innovations in Green Chemistry* and *Going Green* that were held at ACS meetings (GC@UofO, n.d., a). Their website maintains a green chemistry education network that allows individuals who want to move toward green chemistry to find potential collaborators in their geographic region. It also contains an interactive database of green chemistry education materials (GEMs) that can be searched for chemistry concepts, lab techniques, green chemistry principles, and/or target audience (GC@UofO, n.d., b). Because of his deep-seated belief that people who create instructional materials should be involved in research that probes the effect of their implementation, the author was pleased to note that the group at the University of Oregon recently posted a paper on the Social Science Research Network on whether innovation measures actually measure innovation with the intriguing subtitle: "*Obliteration, Symbolic Adoption,* *and Other Finicky Challenges in Tracking Innovation Diffusion*" (Nelson, Earle, Howard-Grenville, Haack, & Young, 2014).

THE RSC GREEN CHEMISTRY INITIATIVE

While writing this chapter, the author noticed fundamental differences between what happened when he entered "RSC" rather than "Royal Society of Chemistry" into the Bing web-based search engine on his computer. Entering the full name of organization took him to www.rsc.org, which is what one might expect. But when he typed only the initials "RSC" into the search engine, the first entry in the list that was generated was "rsc green chemistry."

In 2008, the RSC posted the following note on its website: "... *'Green Chemistry' rather than being a new branch of chemistry is a philosophy that seeks to reduce the environmental impact of chemical processes and products. It can be considered as chemists aspiring to the principles of Sustainable Development*" (RSC EHSC, 2008). Just beneath this note is a button that takes one to a PDF file describing aspects of green chemistry developed by the RSC's Environment, Health and Safety Committee [EHSC]. One can extract several important messages from this small section of a webpage. First, it illustrates the commitment that the RSC has made to green chemistry. It also reflects the connection between green chemistry and both the "health" and "safety" in the EHSC name. When one probes the EHSC website, one finds a posting from 2010 that provides access to a PDF file that describes some of the essential features of the Life Cycle Assessment (LCA) process (RSC EHSC, 2010). LCA's are an extension of the process of global modelling studies and energy audits that were introduced in the late 1960s and early 1970s. They can be thought of as a cradle-to-grave analysis – from design to disposal – of the environmental impact of a product or process, considering both inputs and outputs of the flow of materials, energy and waste.

The RSC has devoted a considerable amount of both financial and human resources to green chemistry in the form of textbooks aimed at introducing this new approach to thinking about chemistry to students, monographs aimed at practicing chemists, a world-class journal Green Chemistry with an impact factor of 6.83 (considerably above the RSC average of 5.46), and numerous examples of how green chemistry can be implemented in the classroom that can be accessed by entering "green chemistry in the classroom" into the search engine on the RSC site.

ACS GREEN CHEMISTRY INSTITUTE® (ACS GCI®)

The Green Chemistry Institute® was created as a not-for-profit corporation in 1997 that became part of the American Chemical Society four years later. The goal of the ACS CGI is to be "*the premier agent of change providing the knowledge, expertise and capabilities to catalyze the movement of the chemical enterprise toward sustainability through the application of green chemistry principles*" (ACS, n.d., c). Under the heading, "*What is Green Chemistry,*" the ACS website makes a series of important points: Green chemistry is not politics, it is not a public relation ploy, nor is it a pipe dream. It is a field described as open for innovation, new ideas, and revolutionary progress. Most importantly, it is the future of chemistry. During one of the annual Green Chemistry and Engineering Conferences, the author was involved in a conversation among a group of industrial chemists who proposed the notion that green chemistry is a global effort to solve what are inherently local problems. If this is true, they argued, different geographical regions will have to take different approaches to solving what might appear to be similar problems. Thus, they argued, green chemistry jobs cannot be outsourced.

OTHER EXAMPLES OF THE ACS COMMITMENT TO GREEN CHEMISTRY

It should be noted that the ACS Committee on Environmental Improvement (ACS-CEI) has created an award for ACS members who are working to incorporate sustainability into chemistry education. The society anticipates that four to six awards will be given each year that will provide travel expenses to the next ACS National Meeting to enable the recipients to present their work.

The topic of green chemistry and sustainability is also addressed by the ACS through both the ACS Division of Chemical Education (CHED) and the ACS Education Division. CHED (2013) is a non-profit, volunteer-run division of ACS members who chose to affiliate with that division. CHED is one of the larger ACS divisions – with between 5000 and 6000 members – that runs symposia on topics related to chemical education at all levels from K-12 through graduate school at national and regional ACS meetings as well as the Biennial Conference on Chemical Education (BCCE). CHED is also responsible for the ACS Exams Institute (CHED Exams Institute, 2013), which prepares standardized exams for use by both K-12 and undergraduate instructors, and CHED was responsible for the creation of the *Journal of Chemical Education* more than 90 years ago (*JChemEd*, 2014).

Symposia organized by members of CHED are occasionally turned into books in the ACS Symposium Series. Three valuable references in this series related to green chemistry and sustainability are the volumes on *Advancing Sustainability through Green Chemistry and Engineering* (Lankey & Anastas, 2002), *Green Chemistry Education: Changing the Course of Chemistry* (Anastas, Levy, & Parent, 2009), and *Sustainability in the Chemistry Curriculum* (Middlecamp & Jorgenson, 2011). The results of DivCHED symposia are also captured in the form of articles published in *JChemEd*. Consider, for example, the paper entitled *Going Green: Lecture Assignments and Lab Experiences for the College Curriculum* (Haack, Hutchison, & Kirchhoff, 2005) that summarized the Green Chemistry experiments that had been previously published in *JChemEd*.

Whereas CHED is a non-profit organization run by volunteers, the ACS Education Division is run by ACS employees who oversee a variety of programs for teachers of chemistry from K-12 through graduate school. The Education Division has five goals: (1) to provide unique, high-quality educational resources, (2) to connect both students and their instructors in ways that lead to professional growth, (3) to provide professional development opportunities, (4) to promote the quality of education in chemistry by supporting the development of guidelines, standards and policies and to evaluate compliance with these guidelines, and (5) to promote excellence by providing infrastructure, collaborations, and the incorporation of best practices.

It was the ACS Education Division that was responsible for coordinating the development of both the *ChemCom* and *Chemistry in Context* curriculum reform projects. The ACS Education Division creates and distributes both print and web-based materials for students through *ChemMatters*® – which has the delightful subtitle "*Demystifying everyday chemistry*" – that regularly includes articles related to green chemistry and sustainability (*ChemMatters* Online, n.d.). The ACS Education Division also schedules periodic webinars in the area of green chemistry and sustainability for practicing chemists.

The ACS Education Division collaborates with the Green Chemistry Institute® to hold workshops for instructors that help them understand how to incorporate sustainability concepts, questions and problems into their curriculum (ACS, n.d., d). The ACS also helps disseminate activities and experiments for green chemistry classified by age level that are grouped into elementary, high school, undergraduate and graduate student categories (ACS, n.d., e). In recent years, the ACS has begun developing materials for use by middle-school students (grades 4th through 6th) under the heading *Celebrate Chemistry* that are available in both English and Spanish (ACS, n.d., f).

BEYOND BENIGN AND THE GREEN CHEMISTRY COMMITMENT

As noted on its website, the mission of Beyond Benign is to provide "*scientists, educators and citizens with the tools to teach and learn about green chemistry, in order to create a sustainable future,*" and its vision is "*to revolutionize the way chemistry is taught to better prepare students to engage with their world while connecting chemistry, human health and the environment*" (Beyond Benign, 2007). Beyond Benign was created by John Warner to provide an approach for scientists involved in green chemistry to reach out to the public because of his belief that:

Green Chemistry provides the perfect platform for communicating the importance of science in providing solutions for many of society's challenges because Green Chemistry inherently minimizes the impact of science on the environment and it is a sustainable approach to chemistry. The relationship between Green Chemistry and the environment provides a uniquely positive, solutions-based starting point for encouraging younger students, who are greatly interested in the environment, to consider positive contributions they can make in any scientific field.

Beyond Benign focuses on three aspects of the Green Chemistry movement: K-12 curriculum and training, community outreach, and workforce development. The K-12 efforts are based on the assumption that the concepts of green chemistry and sustainability will be essential knowledge for all future scientists and educated citizens. Beyond Benign therefore produces lesson plans, curriculum materials and training programs for the K-12 community.

In different contexts, and using slightly different language, the co-founders of the Green Chemistry movement – Paul Anastas and John Warner – have each noted that their ultimate goal is for the term green chemistry to disappear because it has become second nature; the default way of thinking about chemistry. No-one would argue, however, that we are close to having achieved that goal.

As a step in the right direction, a program has been created to bring together a community of supporters of the Green Chemistry movement around the shared goals of: (1) expanding the number of practitioners of green chemistry, (2) increasing departmental/institutional resources devoted to green chemistry, (3) improving connections between academics and industry, and (4) bringing about systemic and lasting changes in the way chemistry is taught by asking students, faculty, departments or institutions, and companies to sign a Green Chemistry Commitment (http://www.greenchemistrycommitment.org/). The goals of the faculty group include uniting the community around a shared set of student learning objectives, providing a way to track progress of the community, and providing direction for outreach and advocacy. The section of the *Green Chemistry Commitment* document devoted to departments or institutions states that the department believes that all chemistry majors should have proficiency in the following green chemistry competencies:

- Theory: Have a working knowledge of the twelve principles of green chemistry,
- Toxicology: Have an understanding of the principles of toxicology, the molecular mechanisms of how chemicals affect human health and the environment, and the resources to identify and assess molecular hazards,
- Laboratory Skills: Possess the ability to assess chemical products and processes and design greener alternatives when appropriate, and
- Application: Be prepared to serve society in their professional capacity as scientists and professionals through the articulation, evaluation, and employment of methods and chemicals that are benign for human health and the environment.

The Green Chemistry Commitment form requires the signature of both the chair of the chemistry department and at least one administrator at the level of dean, provost, or university president.

DIFFERENCE BETWEEN GREEN CHEMISTRY AND SUSTAINABILITY

So far, the author has not tried to distinguish between the terms green chemistry and sustainability (or sustainable development). There are many reasons for doing this, not the least of which is the tendency of people to conflate these terms. But a careful reading of some of the quotes cited so far can help us discriminate between these concepts or philosophies. Consider the EPA’s notion that green chemistry is a step toward a sustainable economy. Or the RSC website that suggests that green chemistry “*can be considered as chemists aspiring to the principles of Sustainable Development.*” Or Beyond Benign’s call for “*tools to teach and learn about green chemistry, in order to create a sustainable future.*” The green chemistry movement might therefore best be considered as a subset of efforts toward sustainable development.

The International Institute for Sustainable Development (2013) noted that the most frequently quoted definition of the term *sustainable development* appeared in the report known as *Our Common Future* from the World Commission on Environment and Development (1987):

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- The concept of *needs*, in particular the essential needs of the world's poor, to which overriding priority should be given, and
- The idea of *limitations* imposed by the state of technology and social organization on the environment's ability to meet present and future needs.

Thus, the Green Chemistry movement and the concept of sustainable development are compatible, but not necessarily synonymous. As noted previously, the author believes that green chemistry not only can be but should be integrated into every chemistry course, regardless of the level at which it is taught or the students who enrol in the course. Examples of sustainable development can and perhaps should be incorporated into these courses as well, but courses that might be best suited for achieving this goal are fundamentally different from the traditional chemistry course(s) so many of us experienced, for better or worse. Furthermore, the justification for the existence of these courses has to be traced back to other motives.

CHEMISTRY IN THE COMMUNITY

It is more than 40 years since Gallagher (1971) called for new ways to show the relevance of science in terms of what became known as science, technology and society (STS) courses. In his paper, Gallagher argued: "*For future citizens in a democratic society, understanding the interrelationships of science, technology and society may be as important as understanding the concepts and processes of science.*" The STS approach to K-12 teaching was fostered in the 1980s by the National Association of Science Teachers (NSTA), which began a report on STS–based science education as follows: "*The goal of science education during the 1980s is to develop scientifically literate individuals who understand how science, technology and society influence one another and who are able to make use of this knowledge in their everyday decision making. This individual both appreciates the value of science and technology in society and understands their limitations*" (NSTA, 1982).

With support from the National Science Foundation, the American Chemical Society brought together a team of university professors and high-school teachers who created a secondary school text known as *ChemCom: Chemistry in the Community* (ACS, 1988). The goal was a context-based, student-centered approach to chemistry. The first edition of *ChemCom* appeared in 1988, and by 2005, over 500,000 copies of the text had been sold and more than 2 million American students had used it in their high-school chemistry courses (Ware & Tinnesand, 2005). Although numerous other factors undoubtedly had an effect, it is interesting to note that enrollment in high-school chemistry courses in the U.S. increased from 32% of the student population in 1982 (before the release of *ChemCom*) to 70% in 2009 (NCES, 2013).

ChemCom's goal, as described by one of its developers, was to "*provoke student interest and involvement in chemistry … by embedding chemistry within society, where chemistry daily impacts human lives, rather than metaphorically confining chemistry to laboratory flasks … and brown bottles*" (Heikkinen, 2010). This commitment to embedding chemistry within society can be seen by noting that the topics in this year-long high-school chemistry textbook were organized around sections entitled Materials: Formulating Matter; Air: Designing Scientific Investigations; Petroleum: Breaking and Making Bonds; Water: Exploring Solutions; Industry: Applying Chemical Reactions; Atoms: Nuclear Interactions; and Food: Matter and Energy for Life (ACS, 1988). The author finds it interesting to note that 20 individuals have been part of the writing teams for one or more of the six editions of *ChemCom*, and while there have been minor changes in the language used to describe the different chapters, the topics have remained the same.

Evidence for the connection between *ChemCom* and the more generalized call for STS-based courses can be seen in a review of contextualized chemistry education efforts in which Schwartz (2006) talks about "*the so-called STS approach*" and then begins the next paragraph by stating that "*A landmark example in this movement is ChemCom: Chemistry in the Community.*"

ChemCom was built on a foundation of 11 objectives, to: (1) give students opportunities to learn basic chemical facts and knowledge, (2) give students opportunities to understand how to deal with societal issues using chemical knowledge, (3) give students opportunities to interpret scientific information, (4) give students opportunities to see how certain personal problems can be solved utilizing chemical knowledge, (5) contain materials that are understandable to students in terms of reading level, graphs, diagrams, and science terminology, (6) help students understand the importance of acquiring appropriate scientific information before making a decision about related societal issues, (7) help students recognize that each solution to a complex societal problem may produce new problems, (8) help students identify alternative courses of action in dealing with societal issues, (9) give students opportunities to learn how to interpret scientific information, (10) help students better appreciate the scope and the limitation of technology, and (11) give students opportunities to become familiar with important issues involving interactions among science, technology and society (Sutman & Bruce, 1992).

The author clearly remembers the concern that was expressed by some of the faculty who taught the first-year general chemistry course at the college/university level when *ChemCom* was first released. Although the target of *ChemCom* was the group of high-school students who were not interested in the quantitative aspects of chemistry but would benefit from exposure to the higher-level thought processes required to approach science and societal issues facing both them and the nation, the question was: What will happen if (or when) students who used the *ChemCom* curriculum enrolled in general chemistry? This question has been addressed by various studies in different contexts, and one finds that students who took *ChemCom* in high-school perform at least as well as those who had used traditional chemistry texts (Sutman & Bruce, 1992; Lynch & Britton, 1993; Sanger & Greenbowe, 1996; Rowe, Montgomery, Midling, & Keating, 1997).

The article by Schwartz (2006) that laid the foundation for the connection between the call for introduction of STS issues into the science classroom and the development of the *ChemCom* curriculum appeared in a special issue of the *International Journal of Science Education* (*IJSE*) that was devoted to "context-based chemical education." Other context-based chemistry curricula described in papers in this issue of *IJSE* included the "*Chemie im Kontex*t" (ChiK) project (Parchmann et al., 2006) and the Salters approach (Bennett & Lubben, 2006).

It is interesting to note the remarkable similarities among context-based curricula for secondary students that were developed for use in fundamentally different geographic regions. We can start with the first and foremost similarity: Different groups working in different environments all came to the same conclusion, a contextualized chemistry course was worth the extraordinary effort required to produce a new curriculum. We can also note that these groups all started from the perspective of a problem that could only be classified as belonging to the affective domain: The traditional course was alienating too many students and there was therefore a need to find a way to motivate students to want to learn our particular science. Furthermore, these projects all started with the assumption that there was a need to broaden the cohort of secondary-school graduates who had been exposed to chemistry as a vehicle for building higher-order cognitive skills.

In the language of an 80-year-old paper with the captivating title "How to Ripen Time" (Bancroft, 1931), the period from perhaps the early 1980s through the mid-1990s must have been an unusually "ripe time" for innovation in both the practice of chemistry – giving rise to the concept of green chemistry – and the teaching of chemistry – giving rise to context-based courses that coupled the process of both "doing chemistry" and "teaching chemistry" with environmental issues. Consider, for example, the intended outcomes of the Salters Advanced Chemistry project (Bennett & Lubben, 2006):

- To show the ways chemistry is used in the world and in the work that chemists do,
- To broaden the appeal of chemistry by showing how it relates to people's lives,
- To broaden the range of teaching and learning activities used, and
- To provide a rigorous treatment of chemistry to stimulate and challenge a wider range of students, laying the foundations for future studies yet providing a satisfying course for those who will take the study of chemistry no further.

The author will assert that these goals could have been – and in one form or another might have been – written by the developers of the *ChemCom* or *Chemie im Kontext* materials. The main storylines used in the Salters Advanced Chemistry project (Bennett & Lubben, 2006) include: (1) the elements of life, (2) developing fuels, (3) from minerals to elements, (4) the atmosphere, and (5) the polymer revolution. Details about how these storylines are used can be found at the Salters Advanced Chemistry website (York, Department of Education, 2014). Examples can also be found of the development of teaching materials of interest to supporters of the green chemistry and sustainability movement that have been integrated into high-school courses that link environmental chemistry with sections on analytical chemistry (Mandler, Mamlok-Naaman, Blonder, Yayon, & Hofstein, 2012.)

CHEMISTRY IN CONTEXT

The *ChemCom* project was such a success, it served as the basis for building a college-level curriculum known as *Chemistry in Context*: *Applying Chemistry to Society* (*CiC*) (Schwartz et al., 1994). The *CiC* project was based on a series of assumptions that reflected conventional wisdom at the time of its inception (Schwartz, 1999). First, non-science majors were poorly served by existing college- or university-level textbooks. Second, knowledge of chemistry "*is important for anyone who hopes to function effectively and vote intelligently in the 21st century*". Third, "*Broader chemical literacy is bound to benefit American society and, not so incidentally, the American Chemical Society.*" A fourth assumption was used to justify the *CiC* curriculum that was not, unfortunately, conventional wisdom at the time: "*... the chief impediment to learning chemistry is not a deficit of intellect, but lack of motivation.*" A major goal of *CiC* was therefore to motivate college- and university-level students to want to learn chemistry.

The ACS sponsored the development of this curriculum because of its long-term commitment to the improvement of the teaching and learning of chemistry. As a member of the ACS board of Directors, the author understands the implications of the fact that the Board included the following as one of the four goals in the society's strategic plan (ACS, 2014): "*Foster the development of the most innovative, relevant and effective chemistry education in the world.*"

The choice of the term "context" in the title of *Chemistry in Context* was designed to bring to mind the idea that the goal of the book was to place the science of chemistry in a social context, stressing ties to economics, political science, and a host of the other social sciences. It was deliberately chosen, however, for a second reason: It comes from the Latin root for the term "to weave together" (Schwartz, 1999). *CiC* was envisioned as a one-semester introduction to chemistry, in which the fundamental core concepts of chemistry would be embedded in the first six chapters. Instructors would then chose from the other seven chapters as they deemed suitable for their students.

The idea behind *CiC* was to build the chemistry course around the following elements: (1) chemistry for a sustainable future, (2) the air we breathe, (3) protecting the ozone layer, (4) the chemistry of global climate change, (5) energy from combustion, (6) water for life, (7) neutralizing the threat of acid rain and ocean acidification, (8) the fires of nuclear fission (9) energy from electron transfer, (10) the world of polymers and plastics, (11) manipulating molecules and designing drugs, (12) nutrition: food for thought, and (13) genetic engineering and the molecules of life. The CiC textbook is now in its 8th edition (Middlecamp et al., 2014).

REFLECTIONS ON THE CONCEPT OF RELEVANCE

It would be useful, within the context of this book, to reflect back upon the language used by the ACS Board of Directors to describe Goal 3 in their most recent strategic plan: "*Foster the development of the most innovative, relevant, and effective chemistry education in the world*" (ACS, 2014). As Stuckey, Hofstein, Mamlok-Naaman, and Eilks (2013) have noted, the term *relevant* is commonly used but seldom adequately conceptualized. The position being advocated in this chapter is fully aligned with the description of the *individual*, *social* and *vocational* dimensions as described by Stuckey et al. (2013). The *individual dimension* can be found in the author's assumption that elements of green chemistry should be incorporated into every chemistry course, at any level. It can also be found in the Green Chemistry Commitment call for a shared set of student learning objectives that assumes that *all* chemistry majors will be proficient in the green chemistry competencies related to theory, toxicology, laboratory skills, and application. The *societal dimension* is aligned with both the idea of adding green chemistry to our courses and the movement toward alternative courses that motivate a far broader range of students to learn life skills that will prepare them to be actively and intelligently involved in societal issues related to the science they study. The *vocational dimension* helps us recognize that only a small fraction of the students who study chemistry at either the high-school or college level enter careers in the chemical sciences, but a much larger fraction of this student population would benefit from applying cognitive skills they develop in our courses to the profession they ultimately pursue.

REFLECTIONS ON THE GREEN CHEMISTRY MOVEMENT

Ten years ago, the National Academies' Chemical Sciences Roundtable held a two-day workshop that focused on what participants felt were the next steps in the evolution of Green Chemistry and Engineering Education (NRC, 2007). The report quotes Doxsee as noting the existence of "*green islands*" that are "*relatively small pockets of activity in green chemistry education.*" And yet it also quotes Collins as stating that "*sustainability is the single most important challenge for our civilization for at least the next 100 years*."

Recently, the ACS GCI® completed a review of the status of green chemistry education in the United States (D. Constable, personal communication). The author of this chapter concluded from reading this report that additional "*green islands*" are gradually appearing and, for the first time, these islands include research-intensive (R1) universities. Consider, for example, the work of the Berkeley Center for green chemistry that brings together faculty and students from the disciplines of chemistry, public health, engineering, natural resources, law and business to offer a series of different courses related to the principles of green chemistry. Or the cross-disciplinary courses in green chemistry at MIT and Northwestern. Arizona State has taken the additional step of creating a School of Sustainability. The ACS GCI® report noted the widespread commitment at the institutional level among colleges and universities to the philosophy of the green environment movement, and yet concluded that only a handful of these examples are accompanied by a similar commitment within the chemistry department to offering green chemistry courses.

Although useful resources such as *Greener Approaches* to *Undergraduate Chemistry Experiments* (Kirchhoff & Ryan, 2002) are available to help instructors introduce green chemistry into their courses, the ACS GCI® noted that most of the green chemistry courses being offered are introductory courses rather than upper-level courses designed to meet the needs of students enrolled in STEM majors. The ACS GCI® report also noted that the majority of NSF funds (79%) devoted to research on green chemistry and engineering were given to large, research-intensive institutions, and yet it was the smaller schools which were more likely to publically promote green chemistry initiatives.

In discussions with colleagues in chemical education from a wide variety of institutions and with staff at the ACS GCI®, the author has reached several conclusions.

- When green chemistry is introduced it is usually the result of a "bottom-up" rather than "top-down" implementation; it is virtually always introduced because of the beliefs or values of one or more faculty (at the bottom of the organization chart), rather than because it was mandated by a department head or dean (who occupies the top of chart).
- When green chemistry is introduced it is done so passionately, by instructors whose commitment to the principles of Green Chemistry and Sustainability are absolutely remarkable.
- Green chemistry is often endorsed with equivalent passion by undergraduate chemistry majors who work with these instructors.
- Green chemistry is usually introduced in a way that is most convenient; by incorporating it into an existing course or courses rather than by creating a separate course, although separate, upper-level courses on green chemistry do exist.
- Although there are examples of institutions where a *Green Chemistry commitment* has been integrated throughout the undergraduate curriculum, they are still rare, and they are most likely to occur in relatively small departments where it is significantly easier to reach the consensus necessary to do this.
- The 21st century is following a pattern that characterized curriculum development/reform projects in the second-half of the previous century: Far more effort has gone into the development and dissemination of green chemistry materials than in the evaluation of the effect of context-based materials on students or their instructors (Bennett & Hollum, 2003; Bennett, Gräsel, Parchmann, & Waddington, 2005; Bennett & Lubben, 2006; Parchmann, Gräsel, Parchmann, & Waddington, 2006; Nelson, et al., 2014).

> Periodically, one encounters papers whose authors are honest enough to note that no formal, large-scale evaluation program was carried out because all of the funding was tied to the development and dissemination of the curriculum materials (see, for example, Bennett & Lubben, 2006).

The author has chosen to conclude with an observation based on his experience as an associate editor of four discipline-based educational research journals. Time and time again, he has seen papers that argue: "*students like …*" Or, alternatively, "*students don't like …*" It is vitally important to remember that different students from the same sample population will have fundamentally different ways of responding to the same curriculum material. When one carefully reads the literature cited in this chapter that describes efforts to achieve curriculum reform, one finds that the goal was not "*to motivate students to take chemistry,*" but to motivate students who were not likely to take the traditional course to take a course that was more suited to their needs and therefore significantly broaden the range of students exposed to the field of chemistry.

Furthermore, it is far too easy to disparage the so-called "alphabet curricula" (e.g., CHEM Study, CBA, BSCS, and PSSC) that were introduced in attempts to reform curricula in the late 1950s. As noted by Heikkinen (2010), the two innovative approaches to high-school chemistry known as CHEM Study and CBA "*catalysed an irreversible change to lab-oriented 'evidence-based' chemistry instruction*." Both programs concentrated on "*building, testing and modifying mental models or constructs to account for regularities noted among phenomena*." Among the changes these curricula introduced were the first step away from local and state control of the U.S. education system, toward a more standardized curriculum. They also represented: (1) the first step toward inquiry-based laboratory activities; (2) a shift from discussions of the properties of substances toward properties of reactions; (3) a change in the role of the instructor from the source of factual content toward acting as a coach, facilitating learning; and, perhaps most importantly, (4) a shift from factual recall toward reasoning and analysis (Heikkinen, 2010). For a comparison of the chemistry curricula created in the 1950s and 1960s with more traditional curricula see Walker (2010). Furthermore, evidence for the success of these programs at reaching the target population can best illustrated by looking at the state of developments in the chemical sciences achieved by graduates of these curricula.

What these courses did not do was meet the needs of the majority of the K-12 student population. Subsequent efforts have addressed that issue, and there is reason to believe that these efforts represent a first step toward addressing the important issue of the role of chemistry along the pathway to what must become sustainable development as defined in the *Our Common Future* report (WCED, 1987).

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15. LEARNING FROM AND ABOUT INDUSTRY FOR RELEVANT CHEMISTRY EDUCATION

Applications of chemistry in, for example, industry, medicine (health), and agriculture have important and highly significant impact on the students' present and future life. That is why learning from and about issues related to industrial chemistry and related businesses has great potential contributing all the three dimensions of relevance of chemistry education, namely the individual, societal, and vocational dimensions. In this chapter it is discussed how these industrial applications of science are influenced by chemistry and how learning from and about them can affect students' attitudes, interests, and their related motivation.

INTRODUCTION

In an era of reform in science education both the content and pedagogy of science learning are being scrutinized, and new standards intending to shape meaningful, authentic, relevant, and contextualized science education are emerging. For example, the Science Education Standards (NRC, 1996) were important steps in identifying the goals for achieving scientific literacy for all students in all levels of schooling. These standards and newer frameworks, suggest that the goal for school science is to educate students to experience the richness and excitement of knowing and understanding the natural world and to engage them intelligently in public discourse regarding debate matters of scientific and technological concerns. It is suggested, that chemistry should be taught to prepare students for academic careers in science and engineering, but in the same time to help them becoming informed and responsible citizens in society, e.g., when it comes to political decisions on applications of science in industry (Ware, 2001; Eilks, Rauch, Ralle, & Hofstein 2013). These future citizens will eventually appreciate how science and technology contribute to their daily life as well as to the society in which they live and operate.

Modern society is highly influenced by scientific advances and its accompanying technological ramifications, e.g. in chemical industry. Consequently, in order to educate the future citizens, chemistry should be taught with appropriate emphasis on relevance to everyday life and its role in industry, technology, and society. However, in general, most of the science curricula developed during the 1960s omitted societal and technological applications of the scientific concepts. Science was taught as a means of advancing knowledge and

I. Eilks & A. Hofstein (Eds.), Relevant Chemistry Education – From Theory to Practice, 285–299.

explanations and not as means for improving society (Hofstein & Yager, 1982; 1986; Hofstein, Eilks, & Bybee, 2011). As a result, many students in the Western world (ROSE, 2005) found their chemistry studies boring and irrelevant and therefore the enrollment of students in chemistry studies either in high school or in higher education decreased significantly (Milner, Hofstein, & Ben-Zvi, 1987). In parallel, there were trends since the 1970s that the general public and the media tended to overemphasize the negative image and the hazardous aspects of chemistry, in the same time neglecting the positive contributions of industrial chemistry to society by producing useful materials, fertilizers and drugs as well as efficient technologies to serve individuals as well as the society. This also contributed in a decline in interest and attitudes towards chemistry and regarding its related applications in chemical industry.

It is suggested that teaching chemistry without incorporating aspects of chemical industry ignores one of the most relevant chemistry-related features of modern life and its technological achievements. Chemistry studies have an important role in educating the future citizens to cope objectively with societal and ethical issues in general and environmental implications in particular caused and to be solved by the chemical industry. Therefore, the emphasis of the chemistry curriculum needs to change from the approach of focusing on the structure of the discipline only (focusing only on theories, key concepts, and processes) to a multidimensional approach, in which students are provided with appropriate tools in order to obtain a balanced view of industrial issues and to educate them to evaluate objectively such topics (Eilks et al., 2013). Kempa (1983), for example, suggested that future developments of teaching and learning chemistry (as well as the development of learning materials) should include a balanced mix of the following interrelated six dimensions:

- The conceptual structure of chemistry;
- The process of chemistry;
- The technological manifestations of chemistry;
- Chemistry as a ‘personally relevant’ subject;
- The cultural aspects of chemistry; and
- The societal implications of chemistry.

It is assumed that these dimensions can be implemented effectively by introducing industrial contexts into the chemistry curriculum. This can be done by using industrial case studies or other related forms of learning and teaching materials about industrial chemistry in the classroom. Different industrial chemistry learning materials as well as instructional techniques were developed for Israeli high-school chemistry education and attempted to place greater emphasis on applied chemistry in chemical industry. Teaching was suggested to take place in its industrial socioeconomic and environmental contexts. This is in alignment with the idea that students are more motivated to study subject matter that they find more relevant to their lives and to the society in which they live than if it appears ‘remote’ (Yager & Hofstein, 1986; Blumenfeld et al., 1991; Holbrook; 2003, 2005, Hofstein et al., 2011). This also is in line with the emphasis of making chemistry learning more relevant to the learner since the context of industrial chemistry allows for contributing to all the three dimensions of relevance of chemistry education, namely the individual, societal and vocational dimensions (Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013).

INDUSTRIAL CHEMISTRY FOR RELEVANT CHEMISTRY LEARNING

Many curricular initiatives in the last decade were driven by research-based findings regarding a lack of motivation to study science in general and chemistry in particular (ROSE, 2005). Deficits were also described concerning the acquisition of applicable knowledge that perceived as being relevant by the students (Schreiner, & Sjöberg, 2005; Bybee, Fensham, & Laurie, 2009). Studies like ROSE and PISA led to the recognition that chemistry learning failed in general to recognize the importance of applications of the theory of situated cognition (Greeno, 1998) towards teaching and learning high-school chemistry. In result many curricula were developed to better connect students' learning in chemistry with meaningful contexts to be perceived by the students as being relevant to everyday life, technology or society. Curriculum innovations developed (in the western world) such as *Salters Chemistry* in the UK (Bennett & Lubben, 2006) *Chemie im Kontext* in Germany (Parchman et al., 2006), or industrial case studies in chemistry education in Israel (Hofstein & Kesner, 2006) represent this development.

Already, in the early 1980s Lewis and Ganiel (1980) suggested that science curricula will be developed in the future should be made-up of three interrelated components namely: Science for the inquiring mind, science for action, and science for the literate citizens (see Figure 1).

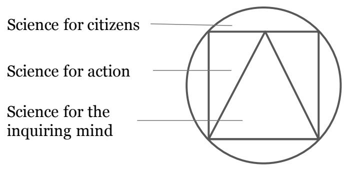

Figure 1. Curricular dimension (based on Lewis & Ganiel, 1980)

One can apply this idea easily in industry-related chemistry education. One example might be the industrial production of fertilizers based on the production of ammonia using the Haber catalytic procedure. The development of ammonia synthesis *is the inquiring mind* component. The *action* dimension is the industrial application of the process, and the *citizens*' dimension is the growing of more and better crops and for the overpopulated world as well as various ecological variables to be considered. With a newer framework suggested by Stuckey et al. (2013) we also see that such a process can contribute to the relevance of chemistry education. It can contribute the individual relevance by intellectual skill development in learning about the chemistry behind the ammonia synthesis and its history, the societal dimension in evaluating an important technology and its potential side effects on society, and the vocational dimension in learning about an important field of future career and potential profession.

Also, during the 1980s, it was suggested that if we attempt to align the chemistry with the student's life experiences it is recommended to organize both the content and the learning experiences starting with the context that makes sense i.e. relevant to the learner (Holman, 1987; Figure 2), one of them might be the applications and practice of industrial chemistry. 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, e.g. in the production of innovative materials or goods. For the majority of the students who will not embark in a career as a chemist such a context will not originate from academic chemist. Thus, having the potential to offer meaningful contexts to the students.

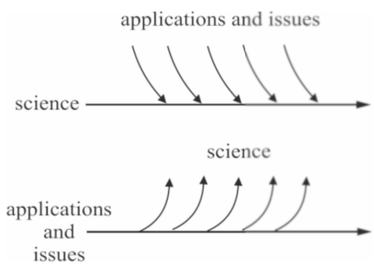

Figure 2. Traditional curricula driven by the structure of the discipline vs. curricula driven by applications and issues (Holman, 1987)

Since the 1980s projects were launched in many countries with the goal of teaching chemistry through a context-based approach. A common characteristic of these 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 to conceptual learning.

A more specific example regarding the idea of starting from an application was suggested by Reid (2000) in Scotland. He suggested a change in the presentation of concepts in the teaching of chemistry (Figure 3).

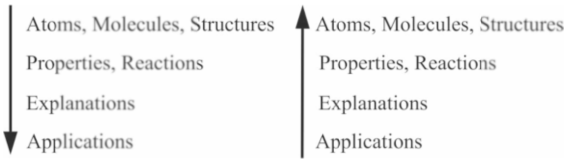

Figure 3. A change in directions (Reid, 2000)

There is no doubt that science in general and chemistry in particular is very important for our world and the society in which we live. Chemistry is central for economic growth and well-fare in every modern society (Bradley, 2005). Many publications emphasis the importance of science in general and chemistry in particular in maintaining the economic wealth of modern societies, thereby justifying both the learning of science as essential for sustainable development in the future (Burmeister, Rauch, & Eilks, 2012), for active participation in society and engagement in societal issues (Roth & Lee, 2004), and getting a balanced and realistic view on chemistry and its industrial applications. Based on this, it is automatically assumed that all students need a certain level of scientific knowledge in order to become literate citizens and, thus, to be able to participate in socio-scientific discussions. This is especially important in our increasingly technological world and it needs learning about the industrial applications of science since the responsible citizen has to make many informed decision in individual consumer behavior as well as on a political level (Hofstein et al., 2011). This makes chemistry learning relevant in its individual and societal dimensions (Stuckey et al., 2013).

However, there is also a need in most of the countries for a sufficient number of qualified scientists and engineers to achieve further scientific and technological developments and to maintain future economic standards of living (EC High Level group on Science Education, 2007). That is why curriculum materials often are influenced by future employers such as chemistry-based (or pharmaceutical) industries or the various academic and educational institutions. In many curriculum projects chemical industry was involved in the development of the curriculum. Examples are the industrial chemistry case studies by Hofstein and Kesner (2006) in Israel or the Salters Chemistry curriculum in the UK (Bennett & Lubben, 2006). The funds originated from the industries with the goal in mind to ensure that in the future there will be enough employees in their plants. In other words that the content (and its related instructional techniques implemented) of the subject matter will encourage more students to seek future careers in the chemical industry. This provides chemistry learning with more societal relevance but also contributes to its vocational relevance (Stuckey et al., 2013).

In the practical section of this chapter we will elaborate on the context-based (and STS-type) approach of chemistry curricula (King, 2002) in its application to industrial chemistry contexts (Hofstein & Kesner, 2006). Such curricula/programs try to contribute to the creation of relevant chemistry education by clarifying the role of science and its related applications in the industry and thus the society of the pupils. The approach makes it possible to develop a chemistry curriculum whose content is closely related to the students' needs, as determined by highly relevant contexts that influence their lives. With suitable selected contexts context-based education has potential for contributing to vocational orientation and promoting learning in the societal dimension of science. It is assumed that this approach provides learners with opportunities to learn structured scientific knowledge, thus giving them a starting platform for more advanced scientific learning, but also orient and prepare them for future careers and their role as responsible citizens. Therefore, context-based curricula are linked to contribute to all the three relevance dimensions. However, the overall contributions to each dimension and their respective weighting can vary significantly regarding the chosen contexts and their aligned pedagogies (Gilbert, 2006).

INDUSTRIAL CHEMISTRY IN THE CLASSROOM

In 2006, Hofstein and Kesner in Israel suggested a specific approach for widening context-based science teaching. They recommended connecting science teaching with businesses and industry applications. This would highlight the interconnectedness of science, the economy and society, thereby offering students valuable insights into possible career chances in science and technology. This extension of context-based science education falls in line with the theoretical foundations of the so-called *socio-scientific issues-based* science curricula (Sadler, 2011; see Chapter 9 by Sjöström et al. in this book). This approach to teaching clearly expresses a wish to make the social dimension of chemistry and its applications a central aspect of classroom teaching (Hofstein et al., 2011). Authentic and controversial issues and debates derived directly from current social affairs should be employed to promote interest among pupils. These topics, however, should not only represent starting points for learning, but should also be the focus for the subject-matter content of the lessons (Stolz, Marks, Witteck, & Eilks, 2013).

This approach not only broadens the contents and objectives selected, but also widens the spectrum of pedagogies implemented (Hofstein & Kempa, 1985; Eilks, Nielsen, & Hofstein, 2013). It is necessary to discuss and train skills for handling these debates in society and participating and shaping such endeavors – all within the scope of teaching science (Marks & Eilks, 2009, 2010; Sadler, 2011). This type of curriculum is most effective for the achieving the goals of discipline-oriented Education for Sustainable Development (ESD) (Burmeister et al., 2012). ESD curricula consciously aim at providing students with skills necessary for participation in social debates and decision-making for sustainability (De Haan, 2006). In this view, this is the essential component which makes science education or any other domain of education relevant to individuals and the society in which they live. The examples from Hofstein and Kesner (2006) can also be viewed as a socio-scientific issues-based curricular approach since it connects science related context and societal issues related to technical applications in industry and businesses, while simultaneously allowing vocational orientation.

The goals for teaching and learning industrial chemistry

It is suggested, that industrial contexts that include issues related to industry and its products used in daily life and its related health and environmental issues have the potential to enhance students' interest and motivation to study chemistry. As mentioned above, such context-based developments in high-school chemistry can be found in various countries such as the UK (Isuyama & Mapeltuft, 1996; Bennett & Lubben, 2006), South Africa (Bradley, 2005), Ireland (Childs & Walsh, 1989), Brazil (Isuyama & Mapeltoft, 1996) and in Israel (Hofstein & Kesner, 1994; Kesner et al., 1997a & b; Hofstein & Kesner, 2006). The key goals of most of these projects were to develop the generation of students to become (in the future) informed citizens who are deeply involved in such issues and be able to make adequate decisions. The idea is that the information about the various industries that they obtain will be balanced and objective regarding the various variables connected to and interrelated with a chemical plant. One of the more long-lasting initiatives (already started in the early 1980s) to connect industrial chemistry to school chemistry was conducted in Israel by the chemistry group at the Department of Science Teaching, The Weizmann Institute of Science (Nae, Hofstein, Mandler, & Samuel, 1982; Nae, Hofstein, & Samuel, 1982; Hofstein & Kesner, 1996; Kesner et al., 1997a & b; Hofstein et al., 2000; Hofstein & Kesner, 2006).

The main objectives of teaching and learning about chemical industries in Israel were:

- To demonstrate the application of basic chemical principles and concepts in industrial chemistry;
- To demonstrate the importance and relevance of the chemical industry to the students personally, and to the society in which they live and operate at present and in the future;
- To develop a basic knowledge of the technological, economic, and environmental factors involved in the establishment and operation of the chemical industry;
- To investigate some of the specific problems faced by a local chemical industry, such as the location of an industrial plant, the supply of raw materials, labor, ways of taking care of the environment, and its related economic aspects;
- To show the differences between a laboratory and an industrial process and the scaling-up steps needed for industrial production design;
- To demonstrate the dynamic nature of industry i.e. changes that chemical industries undergo continuously;
- To provide information regarding economic, environmental, and technological problems which face a chemical industry;
- To show the connection between the chemical industry and social and political issues, environmental issues, and debates, that might include both moral and ethical dilemmas related to industries;
- To provide students opportunities to discuss issues related to location of chemical plants. And finally,

- To present students with opportunities for future career (occupation) in industrial chemistry (vocational relevant).

Issues related to the content of industrial case studies and learning modules

The early attempts (1980-1989) to develop industrial related leaning materials are summarized in a series of studies that were published in the literature by Nae, Hofstein, and Samuel (1982) and by Hofstein (1985). The learning materials that were developed during this period provided an overview regarding the chemical industry in Israel. In a later stage learning materials were written as series of case studies. The case study provides an in-depth approach regarding a certain industrial plant. Each case study includes several facets (and components) of the industrial contexts. These industrial case studies were developed together with instructional techniques and pedagogical interventions. It should be noted, that each student learned one of the case studies. More information about these developments could be found in: Kesner, Hofstein, and Ben-Zvi (1997a & b) and in Hofstein and Kesner (1996). The case study approach enabled us to incorporate and integrate many of the features that are involved in the production processes in the chemistry plant. It also provided us with the opportunity to describe the contexts of real situations and actual problems that exist in the chemical industry as well as topics related to the issues that are involved in the production processes in the chemistry plant, in the use of its products as well as different related problems and their solutions. It also provides us with the opportunity to describe the contexts of real situations and actual problems that exist in the chemical industry as well as topics related to the use of products in everyday life. Our approach was to develop series of case studies that are based on local chemical industries and their related chemical concepts. Two topics were developed as learning units (Kesner, Ben-Zvi, & Hofstein. 1997a).The first one was focusing on the fertilizers industry while the second was based focused on the bromine industry.

The fertilizers case study (*The Story of the Haifa Chemicals Plant*) developed by Kesner (1988) tells the story of an industrial plant located near Haifa Bay on the Mediterranean Sea in the northern part of Israel. The main product of this plant is the double fertilizer, potassium nitrate, $KNO_{3(s)}$.

The Bromine industry case studies, *Bromine and Bromine Compounds* (Kesner, 1990) deals with the production of Bromine in the Dead Sea in the southern part of the country. The uniqueness of the climatic conditions of the region and the high salt concentration of the Dead Sea brines (6M), have influenced the development of a very important industry based on bromine. Bromine and its related compounds are important ingredients for variety of uses such as: flame retardants, deep oil and gas drilling products, biocides for water treatment uses, compounds for steel, rubber, food, and various pharmaceutical products. The interdisciplinary approach is described by Figure 4 illustrating the "Bromine" case study.

As shown in Figure 4, an interdisciplinary approach was adopted and implemented. This includes the underlying chemistry topics and concepts related to the industrial processes and its related technological, societal, economic, and environmental issues, and their interrelationships. All these efforts were conducted in an attempt to involve the students in learning experiences that will eventually enhance their perceptions that chemistry is not only pure but also relevant and applied. Details about the content of the case studies that were are presented in Table 1.

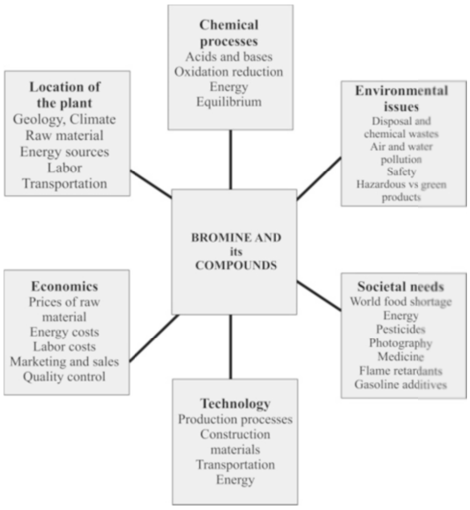

Figure 4. The structure of the bromine casestudy

Pedagogical and instructional considerations

The case study approach provides ample opportunities to vary the classroom environment allowing for the development of wide range of learning skills, thanks to the wider range of teaching and learning activities employed (Pilling, Holman, & Waddington, 2001). Besides making the content contextual and thus relevant to the learner's present and future life, the science education research and literature (Hofstein & Walberg, 1995; Hofstein & Kempa, 1985) recommended varying the classroom learning environment by offering the students different (varied-type) pedagogies and instructional experiences. These might enhance the students' extrinsic motivation to learn chemistry. One of the key elements of teaching about industrial chemistry is to provide the students with opportunities to experience the industrial environment unobtrusively. In order to accomplish this goal two strategies were developed. The first is an Industrial visit: an educational field trip to chemical industry (in which we bring the student to the industry (Nae et al., 1982). The second, developed more recently (Kesner, Frailich, & Hofstein, 2003) is an Internet site designed to provide students and teachers with varied-type curriculum based learning materials related to chemistry concepts and issues (data-bases) and learning experiences (activities) in to the context of chemical industry and daily life applications. This in fact is the approach in which we bring the industry to the classroom. It should be noted that both the industrial visits as well as the Internet site relate to general aspects of chemical industry that are included in the two case studies mentioned above, and also to other industrial chemical plants.

Table 1. Topics and concepts included in both updated case studies (based on Hofstein & Kesner, 2006)

Chemical concepts	Technological aspects	Ecological aspects	Other aspects (societal)
Chemical properties	Industrial processes	Green chemistry	Location of plant
Reaction, reactants, products & conditions	Scaling up	Hazards and risks	Economic aspects, (profitability, supply and demand, production costs etc.)
Bonding & structure	Pilot plant	Toxicity	Manpower considerations
Solvents & solutions	Operation units	Toxic wastes	Licensing
Oxidation-reduction	Construction material	Treatment of wastes	Patents
Acid-bases	Batch or continuous	Disposal of wastes	Quality control
Stoichiometry	Flow chart	Accident prevention	Total quality management
Equilibrium	Separation techniques	Environmental legislation and standards	Marketing & sales
Thermochemistry	Production facilities	Safety rules	Political issues and aspects
Thermodynamics	Conversion & yield	Safe transportation	
Free energy	Energy resources	Recycling	
Kinetics	Energy saving	Recovery	
Catalysts	Storage techniques	Air pollution	
	Transportation facilities	Water pollution	
		Earth contamination	
		Safety equipment	
		Safe storage	
		Purity of raw materials and products	

The instructional design of industrial visits to chemical plants

Field trips are known to be very important and motivating for students in cases in which the actual phenomena or environment is needed to present an abstract concept or an unknown situation (Nae, Hofstein, Mandler, & Samuel, 1982; Orion & Hofstein, 1994). However, this is true only if the field trip is set up properly, with the necessary learning materials and when an appropriate pedagogical approach is used. Based on our past experience (during the 1980s) it was clear that without proper pre-visit preparation the visit could be educationally ineffective and a waste of time. The issue is how to make the visit educationally effective, relevant, and meaningful. Orion and Hofstein (1994), for example, stated that the main role of field trips (outdoor educational activities) is the direct experience with concrete phenomena and materials. They developed an *instructional model* that consists of three phases, which we adapted for our purpose:

- the pre-visit phase to equip the students with the necessary information (chemistry concepts) needed for an educationally effective visit;
- the actual visit to the industrial plant; and
- the post-visit (summary) phase in which a discussion regarding the students' experiences was conducted in the classroom.

It was found by Orion and Hofstein (1994) that in cases that strictly followed the suggested instructional model, students demonstrated a significant improvement in their knowledge and attitudes compared with students from classes that followed a non-structured approach. To make this model adequate for industrial visits, we involved the industrial personnel in the planning of the field trips and in the process of preparing manuals for these visits. Teachers underwent professional development procedures including gaining scientific and technological background about the industrial plant as well as methods to prepare their students for such visits.

During the visits to chemical industries the students are involved in various activities usually performed in small groups (e.g., working on work-sheets on specific questions and small group inquiry tasks). At some of the industrial sites they can obtain additional information regarding these tasks from the industry personnel (e.g. laboratory and engineering personnel). In some of the industrial sites students perform chemical analyses and test-tube experiments that simulate the industrial process. Their findings and observations are recorded and are later used for the post-visit discussions and deliberations.

Although important and educationally effective, very often teachers who plan and conduct such events face many logistical problems. Among these problems are the communication with industry, transportation costs, school schedule, and safety regulations. In an attempt to overcome all these problems a link center was established at the Weizmann Institute of Science: the Israeli Chemical Industry-Education Link Center (ICIELC). This center is directly responsible for providing information, background materials, ideas for school visits in industries, and many others initiatives that are intended to strengthen the link between the educational system and chemical industries in the country. This center helped teachers to communicate with industries and provided support to overcome some of the logistical problems (Hofstein & Kesner, 2006).

In order to provide teachers and students with effective alternatives (in cases in which field trips were not accessible) vicarious alternatives such as films, overhead transparencies, and more recently an Internet site on which we shall elaborate in the next section were developed.

The use of an Internet site to inform students about chemical industries

It is suggested that website can provide an excellent source for data and general information about chemistry-based industrial plants. More specifically, the learner can obtain information about: products environmental issues, location of the plant and other relevant information related to the case-studies that they learn. It should be noted that the website can often be changed to align with new ideas, new products and new related technological and societal issues. The dynamic properties of the Internet, including the possibility of easily performing changes, can serve as an excellent tool for refreshing and updating the curriculum with new subject content and its related pedagogy (Alister, 1999).

An Internet site: "*General Chemistry and Industrial Chemistry for the Service of Mankind*" (http://stwww.weizmann.ac.il/g-chem/learnchem) was developed for the use of all chemistry teachers and students in Israel (Kesner, Frailich, & Hofstein, 2003). The Internet site was constructed to complement and enrich the teaching materials with the industrial context of chemistry and relevant daily life implications as well as to encourage integrating ICT into chemistry studies. By doing so, the site can serve as a source of information as well as a source for classroom and laboratory activities, and can enable students to enhance their investigative and thought process skills. The site is accessible to all and is intended to serve all 10–12th grade (age 15-18) students who study chemistry in Israel.
The site was constructed so that it will be dynamic, appealing, and captivating, up-to-date, user-friendly, applicable to diverse types of students, interactive by involving the students in the learning process, and based on ICT principles. It was constructed so that the chemistry teachers will have maximum flexibility in choosing the activities that will be aligned with their teaching style and in addition, will be suitable to the cognitive ability, learning style, and motivational pattern of their students.

CONCLUSION

One of the key goals for teaching issues related to industrial topics and is to enhance the students' perceptions regarding what they learn about industrial chemistry has impact on their current and future life. In other words that what they study is *relevant*. The question is what is relevant and for whom? Knamiller (1984) connected his perceptions regarding relevance to the question of consequences and fulfilling of personal needs. Together with the more recent literature discussed so far, the use of the term relevance and its connection to other socio-psychological terms in the science education literature can be grouped in five main categories, even though distinctions between them is not always clear and very often different papers overlap the different meanings of the term more specifically:

1. Relevance used as a synonym for student interest (Childs, 2006; Ramsden, 1998; ROSE, 2004).
2. Relevance used as students' perception of meaningfulness for understanding contexts connected to their lives (Gilbert, 2006; King, 2012; Lyons, 2006; Mandler, Mamlok-Naaman, Blonder, Yayon, & Hofstein, 2012).
3. Relevance connected to student needs, which is used as a synonym for importance, usefulness or needs-matching (Keller, 1983; Simon & Amos, 2011).
4. Relevance viewed in the sense of real-life effects for individuals and society, e.g. in terms of growing prosperity and sustainable development by the application of science and technology to societal, economic, environmental, and political issues (De Haan, 2006; Hofstein & Kesner, 2006; Knamiller, 1984).
5. Relevance viewed multi-dimensionally and applied as a combination of selected elements borrowed from categories (Aikenhead, 2003; Kahl & Harms, 1981; Newton, 1988a, 1988b; Rannikmäe, Teppo, & Holbrook, 2010).

Based on this analytical approach, we suggest applying the idea of relevance to science education with more thorough attention to the idea of consequences. These consequences of 'relevance' can be much broader than simply meeting the perceived interests or desires of the learner or to influence the learners' cognitive development. Consequences also encompass real impacts in a socio-economic means, on the students' physical and material life (today and in the future). Also, these consequences need to be taken into account when the question of relevance of science education is raised. This more open view, coming from the idea of considering consequences, suggests potential dimensions that the question of relevance of science education might encompass. Based on the historical reflections discussed above, we have already seen that there can be different fields of consequences where science education or a lack thereof will be of relevance, e.g. skills for acting in society or abilities to get a well-paid job in the workplace.

It is suggested that industrial case studies taught in its holistic approach (see Figure 4), can serve as a platform for the development all the above mentioned relevant dimensions namely the individual dimension for example: conceptual chemistry learning, technological applications, use of materials developed in the industrial plants. The societal dimension to include for example: environmental issues and location of industrial plants. The vocational dimension: the industry as a possible, future, work place.

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16. THE ROLE OF COOPERATIVE AND WORK-INTEGRATED EDUCATION IN CHEMISTRY CAREER CLARIFICATION

In this chapter I argue that an innovative educational approach involving dual sector learning known as cooperative and work-integrated education is a sound way of enhancing student learning of chemistry. I begin by defining cooperative and work-integrated education and detailing its reported benefits based on empirical research. I then consider what is known about how this approach enhances the learning of chemistry, and illustrate this with a number of case studies. A key message is that the learning of chemistry and coming to understand what it means to be a chemist, is better achieved when students learn chemistry by doing 'real' chemistry, and doing this chemistry in a 'real life' chemistry workplace, working alongside professional chemists. From such experiences students gain a much more sophisticated understanding of chemistry, its nature, its role in industry, and the skills and attributes of a chemist. Such experiences contribute to career clarification, because students know what the working life of a chemist really is – something they found to be very different from traditional stereotypes, and indeed very different from what even they as chemistry students thought it was.

INTRODUCTION

Cooperative and work-integrated education is a strategy of education that combines academic learning in the classroom with real-world practice in a relevant workplace. Here it is argued that this real-world experience in the form of work-based placements or work shadowing serves to enculturate learners into a particular community of practice and helps students engage in 'border crossing' into the sub-culture of chemistry. This experience, undertaken as part of an educational program, thus eases the passage of students into chemistry-related careers. From the experience they come to understand something of the world of chemistry and the chemist.

I. Eilks & A. Hofstein (Eds.), Relevant Chemistry Education – From Theory to Practice, 301–315.

COOPERATIVE AND WORK-INTEGRATED EDUCATION

History of cooperative and work-integrated education

Herman Schneider, the Dean of the College of Engineering of the University of Cincinnati, is usually credited with 'discovering' what he termed the Cooperative System of Education. Schneider did not explicitly define the system, but he identified the following characteristics of this pedagogy (Groenewald, Drysdale, Chiupka, & Johnston, 2011, p. 18):

- The system aims to tie theory and practice together in that the student also completes an apprenticeship, which is as equally carefully worked out as the theoretical curriculum;
- Teachers coordinate both the on-campus study and commercial-field experience in order that the practical work provides the highest possible educational value;
- The detail of the practical work is carefully arranged and knit together in an orderly fashion with the theory in a uniform well-coordinated scheme; and
- The aim of the coordination is the establishment of an intimate tie between theory and practice.

Hence, cooperative education very much seeks to link theory to practice, and a key aspect of cooperative education is that it involves time in a workplace engaged in work relevant to the learning/program of study.

Although Schneider is widely regarded as the founder of cooperative education – a pedagogy that is now interpreted as a way to integrate theory and practice (Sovilla, 1988), there were earlier examples in the literature such as the mediaeval guilds, and the so-called sandwich education programs like that offered at the Sunderland Technical College in England from 1903 (Carlson, 1999). The key idea of Schneider's model is that theory is taught first, and this is followed by contact with real life experiences, an approach it is argued aids comprehension of the workings of theory, and where they operate (Eames & Cates, 2011).

A large proportion of cooperative education programs are provided by higher education institutions, although these are of increasing interest at the compulsory school level. The ensuring description provides an overview of the history, development and reported benefits of cooperative education and is followed by a description of school-based programs. The chemistry case studies discussed later provide examples of how cooperative and work-integrated education aids in chemistry career clarification.

Development of cooperative and work-integrated education

Sovilla and Varty (2011) identify three distinct phases in the growth and development of cooperative education: the first 50 years (1906-1956); the Federal funding years (1968-1996); and the modern era (1996-present). The focus here was on the US, where cooperative education began and flourished. Sovilla and Varty observe that after a modest beginning in the early years as a consequence of US

Government Federal funding, the pedagogy went through a massive expansion. It was about this time that the approach became widespread internationally (Coll, Pinyonatthagarn, & Pramoolsook, 2003; Hansford & Stonely, 2011). Unfortunately, as often happens with uncontrolled growth, there were some 'growing pains', and this expansion resulted in some significant quality issues as educational institutions (both public & private) fought over the government's largesse (Table 1).

Table 1. Key issues arising from the rapid expansion of cooperative education(co-op) (Sovilla & Varty, 2011)

Issue	Comment
Emphasizing enrolment over program viability & quality	Institutions knew, or perceived, that to receive continued funding they needed to increase enrollment annually, so directed most of their energies accordingly.
Encouraging immediate campus-wide implementation	A strong sense that officials placed a high value on programs that proposed implementing co-op institution-wide.
Building programs without the benefit of experience	Even though a few experienced educators published guides for building successful programs, in early years, recommended strategies were either ignored or were unknown.
Perpetrating the myth that co-op is right for every institution	Some subject areas are very traditional, and unreceptive to having co-op as an integral part of the curriculum.
Developing new programs outside of the academic mainstream	Staff who do not perceive cooperative education as an integral part of the program that helps achieve curriculum goals, quickly lose interest.
Academic credit issues impact on the evolution of programs	Public institutions that received money based on credits earned lost revenue when students were on co-op and not registered for any credit hours. Pedagogical rationale came later. This led to hostility between co-op staff and teachers.
Superficial institutional commitment	Many programs failed because the institution was unwilling to make the institutional and curricular changes necessary for a viable program. Seldom did they commit their own money to the project.

Modern conceptualizations of cooperative and education

A feature of the expansion of cooperative education that accompanied the growth during the federal funding years was a plethora of models or 'flavors' as educational institutions sought to develop programs purely to gain access to funding. In addition to the quality issues identified above, this led to an extraordinary variety of programs that purported to be 'cooperative education' when they possessed only the most modest component of Schneider's vision. For example, anything involving experiential learning was considered cooperative education (Miliszewska, 2008), as were internships and work experience or work shadowing (i.e., buddying up with a worker/professional). This legacy of diffuseness about what we actually mean by cooperative education haunts us to this day (Coll, Eames, Zegwaard, & Hodges, 2002).

Schneider saw pure cooperative education as consisting of alternating periods of work and on-campus learning in multiple iterations spread throughout the entire program of study. If one were to accept this definition then much of what was labeled cooperative education in the past (and arguably today) would not meet the criteria.

Most modern commentators say that even if we do not necessarily need multiple, alternating periods of work experience (e.g., in a capstone internship only one placement is done at the end of the program) we do need the on- and off-campus learning experiences to be *integrated* in some way. This type of thinking led to the relabeling of cooperative education as *work-integrated learning* (WIL), and accordingly many professional associations labelled themselves as such (e.g., as happened in Australia). Interestingly, Coll et al. (2009) in a major cross-disciplinary, national, study reported that the notion of integration, whilst widespread in the rhetoric of most cooperative education programs, appears to be something of a myth (see also Coll & Zegwaard, 2011). So we say we might *claim* we integrate on- and off-campus learning, but struggle to produce much evidence as to how this is facilitated. Coll et al. (2002), sought to identify key characteristics that must be present if we are to honestly label our programs cooperative or work-integrated learning. These are detailed in Table 2.

The most recent, and thus contemporary, labelling of this type of educational approach is that which forms the label used in the title of this chapter; viz., *cooperative and work-integrated education*, and this is the label used now by the sole world professional body – the World Association for Cooperative Education (WACE)[1]. The shift in terminology from *work-integrated learning* to *work integrated education* seeks to make the point that in these programs learning and teaching are inseparable and that these programs are a three-way educational partnership between the student, the educational institution and the host employer/organization. This notion of cooperation is what gives the pedagogy it name, and is illustrated in Figure 1.

[1] Rather ironically, WACE retained the name *World Association for Cooperative,* rather than shifting to *World Association for Cooperative and Work-Integrated Education* – the feeling was that the WACE name had a strong market presence and thus branding was an issue.

Table 2. Key components of cooperative education and work-integrated learning (Coll, Eames, Zegwaard, & Hodges, 2002)

Issue	Comment
Identification of placement objectives before placement begins	The objective of placement is to develop content knowledge, provide career clarification & gain soft skills.
Integration of on- and off-campus learning	Integration of on- and off-campus learning needs to be facilitated in such a way that students take knowledge gain on campus into the workplace and vice versa.
Responsibility of finding work placements	A staff member from the educational institution needs to facilitate securement of work placement if we are to maintain quality.
Paid or unpaid work placements	Paid placements are desirable; if not possible the work needs to be authentic and of value/importance to the host employer.
Credit on non-credit bearing placements	Placements need to be credit bearing if they are to be taken seriously by students.
Single or multiple work placements	Multiple placements are preferred, if not possible placements need to be of a reasonable duration (say 3 months fulltime).
Assessment of learning on work placements	Placements need to be assessed and any assessment needs to incorporate employer input.

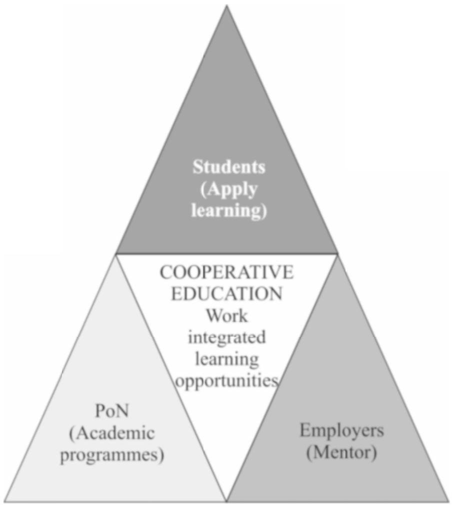

Figure 1. The three-way partnership model that underpins cooperative & work-integrated education (Polytech of Namibia (PoN), Centre for Cooperative Education).

Reported benefits of cooperative and work-integrated education

The notion of adding to a students' skill base by combining or integrating on- and off-campus learning is so intuitive it is tempting to assume it works; it just seems such a good idea. After a fairly slow start to the research base (Bartkus & Higgs, 2011), there is now a substantial corpus of research to the pedagogy generally, and in particular to the reported benefits of cooperative and work-integrated education.

The literature suggests, perhaps surprisingly, that all three partners (i.e., students, employers and educational institutions) benefit from participation in co-op programs. Benefits for each cohort were captured in substantial reviews of the literature reported in the *International Handbook for Cooperative and Work-Integrated Education* published in 2011, and these are summarized in Table 3.

Much of the success of cooperative education is attributed to close matching a student with employment in their discipline and in an appropriate organization (Coll & Eames, 2000). It is this which facilitates career clarification, the theme of this chapter, discussed in more detail below.

Table 3. Reported benefits of cooperative education and work-integrated learning (Dressler & Keeling, 2011; Braunstein, Takei, Wang, & Loken, 2011; Crump & Johnsson, 2011)

Cohort	Examples of reported benefits
Students	
-academic benefits	Reflection, motivation to learn
-personal benefits	Self-confidence
-career benefits	Career clarification & advancement
-work-skill development benefits	Technological knowledge
Employers	Better performing workers
	Lower recruitment costs
	Better loyalty & retention
Educational institutions	Market differentiation
	Recruitment,
	Curriculum development

MODELS OF COOPERATIVE AND WORK-INTEGRATED EDUCATION

Traditional models of cooperative and work-integrated education

As noted above, cooperative and work-integrated education is dominated by undergraduate or higher education programs. The models used, however, are many and varied. Classic or traditional programs are those like engineering which Schneider promulgated, in which there are alternating periods of work placements, and on-campus teaching (Todd & Lay, 2011). Also common is the internship, typically a capstone where a single placement is done at the end of the taught program (MacNamara et al., 2012). The other most common approach is where students do an industry-based project; also often as a capstone, final-year project (Smith, McKay, Holt, & Challis, 2008).

Contemporary models of cooperative and work-integrated education

Recent times have seen a proliferation of other models of cooperative and work-integrated education. As noted above, these include almost any form of experiential learning, and work shadowing along with service learning (Hammersley, 2013). Some professional associations such as that in Australia have deliberately gone down this pathway in an attempt to be more inclusive.

For example, what was *Work-Integrated Learning Australia* (WILA), became the *Australian Collaborative Education Network* (ACEN). This inclusiveness has been extended worldwide with WACE (2013) now defining cooperative and work-integrated education as "*an encompassing term that includes: cooperative education, internships, semester in industry, international co-op exchanges, study abroad, research, clinical rotations, service learning and community service*" (p. 2).

The argument here is that all of these experiences produce a better skilled, more rounded graduate with skills that would not be obtained through conventional on-campus learning – experience, then, is king.

Cooperative and work-integrated education at the high school level

Whilst the literature suggests that cooperative and work-integrated education provides a variety of benefits for students generally, at the high school level it seems it is used mostly for the purposes of career clarification and vocational training (Agrawal, 2013; Careers New Zealand, 2013; Puyate, 2008), often when the school itself lacks specialty equipment. The model most used then is where school students learn vocationally useful skills such as in the trades (construction, electrical work, etc.) in industry, and this helps them both gain and understand what skills they need to become a professional tradesperson (Dasmani, 2011). In the school system work experience is seen as "*any paid or voluntary time that you spent in a workplace to get to know it better … which can range from a one-off visit to a workplace, to cadetships that last months*" (Careers New Zealand, 2013, p. 5).

In New Zealand, as an example, a common model is *Gateway*, where Year 11 to 13 students spend one day a week in an industry work placement, which can be counted towards formal qualifications. Other examples include programs reported in Portugal where school students engaged in work experience for *Students During the School Holidays* in order to promote direct involvement of young people with the Portuguese scientific community (Marques, Praja, & Thompson, 2002). Research units and institutes hosted groups of secondary students, and there was a sub-program *Geology in the Summer* where geologists organized and led field trips for students and the public. These trips included visits to sites such as cliffs, natural parks (national parks, nature reserves), quarries, and mining operations. Another program *Astronomy in the Summer*, gave people on holiday, and on the beach, the opportunity to use telescopes and to listen to informal talks by astronomers and therefore to learn about planets, stars, nebulae, and meteors.

Cooperative and work-integrated education and chemistry learning

There is a long history of chemistry cooperative and work-integrated education. Indeed, with the origins of the system being in engineering, the sciences (including chemistry) soon followed (Zegwaard & Laslett, 2011). Like most programs, chemistry cooperative and work-integrated education is dominated by the higher education level. For example, Beard, Coll, and Harris (2001) report on the experiences of a chemistry undergraduate working on a 12-month work placement at an analytical chemistry laboratory, saying that there was good evidence of the professional and personal growth for the student, which occurred as a result of student-employer negotiated placement objectives and on-going support during the placement (see also Wong & Coll, 2001).

An interesting example of the practice of chemistry cooperative and work-integrated education is the so-called 'Analytical Club', a club formed as a result of direct feedback from UK-based chemical industries and their angst over graduate skills. The Club was formed to "*have an advisory role in overseeing the design and operation of degrees in analytical and environmental chemistry [and] facilitate a close relationship with 'local' chemical companies*" (Ward & Jefferies, 2004, p. 16). Here, then we see the entangled nature of the partnership model, with chemical companies providing valuable curriculum input, which results in better graduates more suited to graduate employment – a full circle of iterative enhancement that relies on all parties contributing.

There also are a number of international student co-op exchange arrangements for chemistry students allowing students to gain valuable international experience that would not be easily achieved at home. So, for example, students from New Zealand and Australia can gain experience working at large scale multinational corporations that are not present in their home countries; equally students from the UK can gain exposure to chemistry careers in smaller, more intimate, SMEs – something not that common in the UK.

The benefits for chemistry students', employers and educational institutions are much the same as reported for other sectors (Table 3). There are, however, numerous reports of chemistry-specific skills and knowledge gained as a result of student participation in cooperative education work placements or internships. Students mostly report gaining specific *technical* skills, and as might be expected, this tended to be related to the use of specific chemistry instruments. For example, Wong said she learned how to operate a variety of modern analytical instruments such as GLC, HPLC and so on; skills and techniques that she said never got access to in her formal schooling at high school or during her university education (Wong & Coll, 2001). Few high schools have access to modern scientific instruments although learning about chemical instrumentation features in many school curricula (Coll & Taylor, 2008). Even at university students seldom gain much direct, hands-on access to expensive modern chemistry instruments (Beard, Coll, & Harris; Zegwaard & Laslett, 2011). Hence, work placements or cooperative education can help integrate learning of chemistry content and skills between the formal and informal sectors (see Chapter 19 by Coll & Treagust in this book), by exposing students to theoretic learning and practical skill acquisition in a manner that would be difficult otherwise – mostly due to the cost of instruments. This integrated approach to chemistry learning means students learn in two educational contexts; the formal sector (be it school or university), and the workplace, and gain complementary practical and theoretical chemistry skills.

This acquisition of technical chemistry skills is highly desirable to students, who are strongly focused on the acquisition of chemistry content knowledge and practical skills – mostly because they think it will improve their employability (Coll, Zegwaard, & Hodges, 2002). The science education literature, however, suggests that if we wish to produce scientifically-literate citizens or, or work-ready chemistry graduates, we need to help chemistry students and aspiring chemists also to learn the *research methods and inquiry approaches used by modern chemists* (Çalik, Turan, & Coll, 2014; Coll, Taylor, & Lay, 2009). There is now evidence in the literature that cooperative education does achieve this. How this occurs is developed in depth below in the case study reported by Eames, but it seems widespread, and it is based on an apprenticeship model of learning. So like motivation to study chemistry, or to continue with chemistry studies, learning about chemistry and its methods is best gained by immersion in an environment where chemistry is actually practiced; viz., a chemistry workplace. It is argued in the cooperative education literature that this is more effective than, for example, chemistry competitions or science fairs, and the like (Eames & Bell, 2005).

Modern school chemistry curricula not only tend to focus on learner centered education and acquisition of high level cognitive skills such as inquiry, but also seek to *enhance student attitude toward chemistry* (or the sciences) and their disposition toward chemistry. This is motivated by a desire to encourage more students to study the sciences (an engineering), particularly the so-called enabling sciences like chemistry and physics so as to produce more graduates in the sciences. This is typically driven by the notion of a knowledge economy and the view being that graduates in the fundamental sciences like chemistry are needed to innovate and ensure enduring economic growth (Coll & Taylor, 2008). Again there is evidence in the cooperative education literature that attitude toward chemistry, and motivation to engage in further chemistry learning is enhanced by chemistry work placements. For example, Zegwaard and McCurdy (2014) report that chemistry students were, as a result of work experience where they were working alongside research chemists – encouraged to continue on into postgraduate studies, to the extent that they felt obligated to continue: "*I kind of felt that I should because I'd been one of the top students in the Chemistry Department, so I felt it was kind of expected to go on and do a masters degree*" (Zegwaard & McCurdy, 2014, p. 20).

COOPERATIVE AND WORK-INTEGRATED EDUCATION AND CHEMISTRY CAREER CLARIFICATION

An in-depth case study of chemistry career clarification within a cooperative and work-integrated education program was conducted by Eames as part of a longitudinal PhD study spanning nearly six years. This work represents something of a landmark in educational research in cooperative and work-integrated education, in that it was one of the first studies in the area to be derived from a sound theoretical basis, and modern theories of learning. Bartkus and Stull (2004) commented that much research in the sector focused on what Eames referred to as 'operational outcomes' (e.g., did students get better jobs, get jobs more easily, get paid more, etc.), and lacked robust theoretical underpinnings; something echoed by other commentators (see e.g., Eames & Coll, 2007).

Eames's work drew upon sociocultural theories of learning to consider the learning that occurs on placement (Eames & Bell, 2005; Eames & Coll, 2006). Of particular relevance here is Joe's[1] story an in-depth longitudinal tracking of the learning experiences of a young chemistry undergraduate (amongst others) as he became enculturated into the community of practice of professional chemists. In this fascinating story, we see Joe begin to understand how messy real research is, and his burgeoning insights into the world of the professional research chemist. So Joe began with rather naive views of chemistry research formulated from his school learning experiences: "*I see it essentially as a logical process of hypothesis, experimentation and assembling the results and interpretation of those results. Just going through that entire scientific process*" (Eames, 2003, p. 10). This is a highly traditionalist view of scientific inquiry; one which fails to match current thinking in science education (Coll & Taylor, 2004), and which is dominated by naive notions of a scientist slavishly adhering to the 'scientific method', and evidences lack of understanding about scientific thinking and scientific habits of mind (Coll, Taylor, & Lay, 2009).

However, after having completed one 3-month and one 9-month relevant full time work placement within a chemistry research group at a publically-funded scientific research institution, Joe's view changed dramatically. In particular, one can sense his wonderment at the creative aspect of inquiry:

> It's sort of taught me that often the research can't be fully structured, like right from the beginning, with contingency factors having to be allowed for and often interesting sort of tangents might arise that are worth pursuing or can be pursued later. So it is sort of like a spider's web, if you like, of ideas and knowledge that have been generated. (Eames, 2003, p. 12)

What Joe appears to have engaged in here is what Aikenhead (1996) refers to as *border crossing*, where students cross over from their world into the subculture of science. Aitkenhead says science is so different in its way of thinking that leaning science is like entering a new culture or subculture, where the rules are very different from everyday life (Aikenhead, 1996, 1997).

From a career clarification perspective, by the time Joe had completed his full program of study (including both work placements) he had reached the conclusion

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[1] 'Joe' is a pseudonym.

that the work placement component of his program in particular helped him develop useful skills, and understand the application of chemistry in a real world situation:

> This placement has been a wonderful experience which has equipped me with a whole range of new experimental, analytical and *social* skills that will be of great help to me in future employment. It has also helped to stoke the fires of interest and enthusiasm within me for chemistry and I will enter this year with a much clearer perception of chemistry in action in the workplace [added emphasis].

Eames (2001) interpreted Joe's experiences through a sociocultural lens, and decided that the enculturation process occurred via the use of Vygotskian psychological tools (e.g., use of language, technical equipment, etc.), an appreciation of distributed cognition (e.g., Joe came to realize knowledge was not solely resident within the expert chemist, but included documents and other individuals such as technicians) as he engaged in legitimate peripheral participation (i.e., he worked alongside the chemists in the manner of an apprentice), and as a consequence came to a more holistic and comprehensive understanding of what it means to 'do' chemical research, and what it means to be a chemist.

A second example, that precedes Eames work, but which shows how students learn, and how they see chemistry work placements as important enablers of career clarification is international exchanges of chemistry students such as that between the University of Waikato in New Zealand and Surrey University in the UK. This exchange programme has operated for over 30 years, and numerous chemistry undergraduate students have gained chemistry work experience, and developed chemistry careers from participation. Interestingly, there are two key themes that emerge from a cross case analysis of reports of these programmes, and these themes are consistent with the discussion cited above and Eames work.

First, is the acquisition of skills mentioned above (e.g., Beard, Coll, & Harris, 2001; Wong & Coll, 2001). But what seems to happen in work experiences is that aided by the appropriate pedagogical 'structures' (in this case a requirement to keep a reflective journal) is that the student engages in metacogniton. This can be seen in Wong's reflection and review of the learning that occurred during her work placement with a major multinational corporate beverage and food manufacturer in the UK (Wong & Coll, 2001, p. 15):

> I anticipated using HPLC a lot during the year and gained much firsthand experience with auto-sampling and manual injection processes. I enjoyed using manual injection HPLC during caffeine analysis because I had to check all the tubing and filters at start up and monitor the pressure for blockages or leaks. This meant I came to know the instrument in a much more detailed fashion than if I had dealt with a fully automated instrument. Likewise, I learned valuable skills from spending time putting pieces of the HPLC together. From this experience, I found that I learn more effectively from practical aids than aural or visual aids.

This is quite sophisticated thinking (instrumental problems became learning experiences), by a student who whilst very academically able, was not much used to thinking about her learning. Second, she gained insights into an industry which she previously didn't realize had much to do with chemistry: "*It is evident from the above description of tea production and the composition of tea leaves that there is much chemistry in this popular beverage.*" Such insights open students' minds to chemistry careers they would not have even realized existed. In terms of skill development, as well as finding new areas requiring chemistry knowledge (i.e., the food industry) she seemed surprised to learn 'soft skills', and to come to realize that these were also important if one were to become a chemist (this echoes. Joe's story reported by Eames, see above). These skills set as learning objectives "*were negotiated at the beginning of my placement,*" and like other chemistry students she came to realize the value chemists and chemistry employers place on skills other than purely technical skills (Coll, Zegwaard, & Hodges 2002; Eames & Bell, 2005). Like Joe in Eames story, Wong came to enjoy research, and decided she wanted to continue with research and subsequently completed a PhD in chemistry and worked in a public sector research institute.

Beard was a Surrey student who worked in NZ at the same time Wong worked in the UK as part of the Waikato-Surrey international chemistry placement exchange. Like Wong, Beard set learning objectives, and again these were mostly technical in nature: "*use of leading-edge analytical techniques; FIA [flow injection analysis] in particular, being a continuous process that ensures rapid turn-around of samples. The remaining tasks constitute more conventional 'wet bench' chemistry techniques.*" However, upon guidance by his placement coordinator, he "*sought to gain technical and soft skills,*" with a notion that they "*would be desired by employers.*" A clear career focus here. Again like Wong, he seemed surprised but pleased to appreciate the value of non-technical skills, showing some angst over having to make presentations about his work: "*provided an opportunity to describe my work in a formal setting to an expert and critical audience. Whilst for me personally this represented a daunting prospect, it enabled me to continually monitor and conduct a self assessment of my own progress and performance with regard to communication skills.*" Interestingly, he came to understand the future value of the soft skills gained on placement: "*There will be further opportunities of this nature and I expect to continue to improve in this regard. In addition, I was expected to interact with a variety of staff in the laboratory, and to initiate communication when required.*" Again, this is quite sophisticated appreciation and forward looking. The career clarification spontaneously surfaced, although it is necessary to note that the structured reflection common to the UK and NZ ends of the international exchange probably drove this type of thinking:

> The work placement also enabled me to "test the waters" in the career path for which I am embarking. Prior to this I had little idea of what was involved in becoming a career analytical chemist. Working in a modern analytical chemistry laboratory, alongside professionals and experts, provided me with an excellent overview of this career. This will enable me to make an educated choice regarding my future career options.

The notion that setting placement objectives and driving the refection process, whilst no doubt influencing the research outcomes for the present work, is as noted a deliberate pedagogical strategy to encourage higher cognitive development, and indeed career clarification. This is reflected in Beard's concluding reflective remarks about his placement:

> As the student developed skills in some areas, experience and reflection revealed other areas requiring improvement, which were then targeted for remedial action. This process of setting objectives, and constructive, timely feedback, proved to be the key to personal and professional growth, and ultimately a highly successful international placement.

What is particularly interesting about these two cases is that in terms of career clarification they resulted in two quite different outcomes. Wong's case allowed her insights into a different world of career possibilities – in that she had not realized there was much chemistry in the food industry (in her case the tea industry). But in Beard's case he gained insights into the day-to-day life of an analytical chemist, a career he already aspired to.

CONCLUSION

Cooperative and work-integrated education has a long history and nowadays a solid research based that shows students, employers and educational institutions all believe they benefit from engagement in this tripartite educational partnership. A key benefit for chemistry and other students lies in career clarification, something it seems is facilitated by time spent in a relevant work place, working alongside practicing chemist and gradually becoming enculturated into the community of practice of professional chemists, and as a consequence developing deeper insights into careers in chemistry. They develop more sophisticated understandings of the nature and scope of chemistry careers, what it means to be a 'chemist', and where a chemists can and do work.

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17. INNOVATION AND EMPLOYABILITY: MOVING BEYOND THE BUZZWORDS – A THEORETICAL LENS TO IMPROVE CHEMISTRY EDUCATION

'Innovation' and 'employability' are often used in and around chemistry education. In this chapter we explore how these terms can have a meaningful role to play in relevant 21st century chemistry education. We argue that chemistry education, in particular at the level of higher education, faces at least three challenges. We then trace back the genealogies of the concepts of innovation and employability, and identify a way to understand these two concepts in a way that rids them off the current economic connotations and which renders their usage meaningful at the level of pedagogy. We then sketch what we perceive to be the fundamental traits of a pedagogical focus on fostering students' innovation competence and employability. Finally we argue that this focus, in principle, can be a way to ameliorate the three challenges that faces chemistry education.

INTRODUCTION

In this chapter, we argue that it is possible to find a meaningful way to conduct chemistry teaching that fosters students' innovation competences and/or employability. Further, we argue that chemistry teaching for innovation and/or employability holds the key to begin to solve three key problems for chemistry education.

Chemistry education is beset by three challenges. First, higher and upper secondary education is in the process of transforming from institutions of elite education for a select group of students, to institutions that seek to recruit a large proportion of a student population (e.g. Thomsen, 2008). For example, in Denmark, this has led to a 48% increase in students entering universities in the period 2005 to 2013 (Danish Ministry of Science, 2013). Since the emergence of the medieval university in Europe in the twelfth century, this increase in student population is the largest change in the history of universities (Shin & Teichler, 2014). However, the concept of the mass university is not new (Scott, 1995), and as policymakers, educational planners and teachers alike are still struggling with the challenges it has evoked, some talk of post-massification as a present phenomena (Shin, 2014; Trow, 2010). One of the reasons for why higher education still faces this challenge is that antagonistic rationalities about the consequences of the mass-university are still embedded in higher education. One the one hand, we

I. Eilks & A. Hofstein (Eds.), Relevant Chemistry Education – From Theory to Practice, 317–334.

face an egalitarian discourse, which revolves around the idea that we must strive to include more students' across social and cultural boundaries and hence widening higher education participation (Shin & Teichler, 2014). On the other hand, we face an elitist discourse, which revolves around the idea that we must select and protect talented students to compete in the market of world-class universities. Both discourses affect the way we perceive higher education chemistry. In other words, chemistry education is urged to change from a subject accessible by only few elite students, to reach out to include students from non-traditional backgrounds who are alien to the governing practices of academia (Watson, Nind, Humphris, & Borthwick, 2009), yet at the same time, chemistry education is urged to foster and keep the students who are recognised as talented.

Second, chemistry education is challenged in terms of the curriculum and the teaching methods applied. There is a well-researched discrepancy between what we know about students' learning and how study programmes and teaching are organised (Becker, 2010; Johannsen, Rump, & Linder, 2013). In particular, the culturally embedded idea that students first need to learn the theoretical foundations, to have a chance to learn the core science content at all, that learning science is 'back to basics', memorizing, hard work and solid knowledge transmitted by a lecturer, conflicts with the intention of educating students as innovative, creative, sustainable and democratic citizens, who can communicate, negotiate and collaborate in a diverse, global society (Eilks & Byers, 2010; Eilks, Nielsen, & Hofstein, 2013). Therefore there is a call for chemistry education to move towards innovative teaching methods (Eilks & Byers, 2010), and to teach future students the tools of curiosity and to identity problems rather than passively having them transmitted by a teacher: Chemistry should cluster its teaching and research around the exciting and uncertain future rather than the ossified historical past (Whitesides & Deutch, 2011).

Third, chemistry education is challenged in terms of the employment of the workforce of chemistry students. Two thirds of European chemical companies have difficulties recruiting well-educated staff. Both because there is a shortage of candidates with a chemistry degree (which highlights the importance of the before-mentioned challenges of widening higher education participation), but also because the competences that these candidates possess do not correspond with the requirements in the chemical industry (Salzer, 2012). Within higher education increasing attention is paid to the extent to which higher education students are able to transform their capacities and competences into the demands of the labour-market (EU-Commission, 2011). Today, universities are urged to reform themselves and move away from perceiving academic practices as their only concern. Indeed, universities are required to provide their students with a broad range of competences, to ensure that their students are employable. Few studies have been carried out in the field of chemistry education to explore how students' learning within higher education is transferable to the job-market. Therefore a final challenge to chemistry education is to ensure that the employability of students is dealt with in the chemistry education curriculum.

In this chapter we suggest that the notions of innovation and employability can prove to be valuable tools in chemistry education to address all three challenges. But the notions cannot be directly transferred into chemistry education. Innovation and employability are notions that stakeholders frequently use in attempts to steer the development of curricula and teaching practices in science education. In this chapter we will offer an insight into the origin of the notions and the various ways they are applied, and show how the discourses about innovation and employability are heavily embedded in political and economic rationales. Through an analysis of how the notions can be applied to chemistry education, however, we argue that both innovation and employability can be meaningfully applied in pedagogical approaches in chemistry education. In other words, the chapter will discuss how the notions can contribute to the development of students' competences in relevant chemistry education to meet the requirements of the 21st century (Trilling & Fadel, 2009).

INNOVATION

Innovation, why care?

There is a building consensus among policymakers and industry stakeholders that the future economic wellbeing of European societies relies on peoples' innovative skills. Indeed, facilitating future innovation is one of the key areas of concern in the EU commission's 'Europe 2020' strategy (EU-Commision, 2010). The OECD recently emphasised the role of education in this regard: "*The need to empower people to innovate […] calls for high-quality and relevant education as well as the development of wide-ranging skills that complement formal education*" (OECD, 2010, p. 3). There can be no doubt that the focus on 'education *for* innovation' (Nielsen, 2014b) will come to the attention of the field of science education in the near future. In fact, the OECD mentions that "*[s]cience is vital to innovation, especially to generate 'step changes' such as the discovery of the transistor or vaccines*" (OECD, 2010, p. 4).

So far, only very few contributions to science education addressed this topic. The seminal 'Science education in Europe'-report (Osborne & Dillon, 2008) briefly mentioned that there is a shift in society towards valuing "*creativity and innovation more highly than have been the case in the past*" (p. 17). And in a large Delphi study Osborne and colleagues found that many participants of the expert community think that it is important that science students have "*opportunities to be genuinely creative*" (Osborne, Collins, Ratcliffe, Millar & Duschl, 2003, p. 706).

Until recently, the discourse about education for innovation has often been linked to specific educational areas or disciplines, such as business education and engineering. But now there seems to be a building consensus among policy makers and other stakeholders – even on an international level – that *all areas* of educational systems have a role to play in fostering innovation. For example, both the incumbent and former Danish governments have insisted that fostering innovation competencies is a task for all levels and areas of the Danish educational system. Indeed, what these administrations have seen as needed is a general "*change in culture in the educational system, with focus on innovation*" (Danish Government, 2012, p. 8; our translation). Similar trends can be seen in Finland (Finnish Government, 2009), the Nordic countries in general (Nordic Council of Ministers, 2011), Australia (Commonwealth of Australia, 2009), and the US (White House, 2011), and surely in many other countries as well. Indeed, we are witnessing, in the Danish context at least, that innovation is becoming central in most other educational domains at both the university level (University of Copenhagen, 2012) as well as the secondary level. Unfortunately, policymakers and educational scholars often fail to define what they mean about 'innovation'; in particular terms like 'innovation' and 'entrepreneurship' are often used synonymously (Mars & Rios-Aguilar, 2010). There is, therefore, a need to revisit the origins of innovation.

The genealogy of innovation

While most dictionaries trace the origin of 'innovation' back to the 16th century latin concatenation of 'in' ("into") and 'novare' ("make new") (Stevenson, 2010), Godin's (2008) authoritative genealogy traces the term as far back as the thirteenth century – where it denoted changes made to legal contracts. Further, it does seem that the term, until the eighteenth century was used as a pejorative term; denoting dangerous challenges to the existing religious establishment. It was not before the mid-nineteen century's industrial revolution that 'innovation' received its' more positive connotation, where disciplines such as anthropology began using the term as an umbrella term for "*changes in cultural traits, but also inventions in agriculture, trade, social and political organizations ... and technology*" (Godin, 2008, p. 25). This represents a shift from using 'innovation' merely to signify something new, to also signifying an aspect of invention or creation leading to (a more or less desirable) change. Thus, in the mid-twentieth century, many scholars used 'innovation' to signify a *process* of "*technological inventions [that are] used and adopted*" (Godin, 2008, p. 31). A contrasting notion parsed innovation as a *product* – e.g. Rogers (1962) defined 'innovation' as "*an idea perceived as new by the individual*" (p. 13). Still today, innovation is ambiguously used to denote both a process and a product (Gopalakrishnan & Damanpour, 1997).

In the twentieth century, a subfield of economics that was concerned with change and dynamics (as oppose to equilibrium – the traditional focus of economists) began to focus on innovation (Godin, 2008). We owe this movement that 'innovation' today often connotes that the established is destructed by something *novel* (most often a method or a technical product) is *commercialized*. This *economist* definition of innovation is often traced back to Schumpeter (1934/2004), for whom innovation

> covers the following five cases: […] the introduction of new goods […] the introduction of a new method of production […] the opening of a new market […] the conquest of a new source of supply […] the carrying out of the new organization of any industry. (p. 66)

As such, for Schumpeter, innovation is an activity – or *function* – of the entrepreneur in his/her quest for "*creative destruction*" (Pavitt, 2006, p. 105). In many ways, it is this economist rendition of innovation that seems to dominate the public discourse today.

One of the problems that still beset us today is the unfortunate tendency of policymakers and other stakeholders to use 'innovation' and 'entrepreneurship' interchangeably (for a brief discussion of this see e.g. Harding, 2009) – e.g. in the first Danish public mention of 'innovation' in an educational context, innovation was merely treated as the *sine qua non* of entrepreneurs (Danish Ministry of Education, 1995). In order to alleviate this problem, we propose to separate innovation from entrepreneurship in the following way: While innovation signifies the (creative) change to an established practice (often in a valuable way, but not necessarily in the sense of creating an economic value), entrepreneurship is the transformation of a product into economic value (Nielsen, Rump, & Christiansen, 2013).

The different meanings embedded in innovation

As mentioned the term 'innovation' is ambiguous in the sense that it can denote a product or an outcome as well as a process, and the features that recent researchers have used to define innovative processes have been very varied. Clearly, whichever features one focuses on when constructing new curricular will have an impact. Recently, Hobel and Christensen (2012) defined innovation as an ability in way so as to make it meaningful as the aim of education, and in a way that links up to the traditional notion of *Bildung*:

> Innovation signifies that of rethink and improve (that is, not just change) an existing practice in the world in an ethically defensible fashion with actors that are influenced by and act in that practice on the basis of relevant knowledge. (p. 57)

As such, this may be the most stringent definition so far of innovation in an educational setting.

In a recent study (Nielsen, 2014b) of how expert teachers in upper secondary school talk about which criteria should be used for assessing *innovation competence,* it was documented that these expert teachers point to five generic sub-competences all at play in innovation processes revolving around authentic issues from a practice (often involving stakeholders from that practice):

- *Creativity*: The extent to which the student can find, not just idiosyncratic ideas/solutions, but a range of different ideas/solutions, and then sort, prioritise, and extend selected ideas/solutions.
- *Collaboration*: The extent to which the student can take responsibility for a group finishing a task, and be inclusive and versatile when it comes to group work – e.g. by demonstrating that she can utilise how the skills and knowledge of others complement her own.

- *Navigation*: The extent to which the student can use her disciplinary background to decode a task or an issue; assess which information is critical for solving a task/addressing an issue; and take ownership of and plan complex work process.
- *Action*: The extent to which the student can implement her ideas; assess and take risks; and collect information from other sources than the classroom.
- *Communication*: The extent to which the student can analyse how to communicate to a specific target group; can master different communication techniques and methods; and can communicate in an engaging and convincing manner.

This study, while not representative at a large scale, provides a detailed glimpse into how expert teachers think about the aims of education for innovation (Nielsen, 2014b). Most importantly, from this study it was clear that teachers were hesitant to assess their students in terms of whether or not the students' ideas/solutions to authentic issues potentially created value for (that is, improved) a given practice. Rather, the teachers in this study focused on whether the student could reflect upon, and justify their claims regarding, the potential value-creation for the practice involved (Nielsen, 2014b). As such, it could make sense to speak of *preparatory innovation competence as a goal for education* – where this would mean that the educational system should teach students to go through *specific processes* (in which they attempt to improve on issues from authentic practices) in *specific ways* (by being able to be creative, collaborate, navigate, act/implement, and communicate at the proper phases in the process).

Based on this, we could hone in on education for innovation in the following way: Education for innovation signifies teaching and learning aimed at fostering the competency to, individually or together with others, and on the basis of relevant knowledge, (a) generate ideas or solutions to an issue from an existing practice; (b) to asses these ideas in terms of their utility, realizability, and value-creation potential; (c) to implement selected ideas, possibly in sketch-form; and (d) to communicate ideas to different stakeholders.

EMPLOYABILITY

Employability, why care?

The mass university as described in the introduction in this chapter is a phenomenon that challenges higher education in its current form. As more students than previously enter higher education institutions, higher education is no longer a self-contained system with the primary aim to produce students who pursue careers in academia. Rather, higher education is requested to contribute to the development of society in general and the economic growth in particular (Cerych & Furth, 2011; Trow, 2010). As a consequence, the economic value and accountability of universities has become a centre of political attention (Mayhew, Deer, & Dua, 2004). Higher education institutions are urged to ensure that students actually learn the competences requested by and are transferable to a flexible labour market to achieve better economic progress (OECD, 2013; Eilks & Byers, 2010). This economic discourse reinforces the pressure for higher education institutions to transform from universities as institutions for knowledge and research in itself (Knight & Yorke, 2003) to points of departure for students to prepare for encountering the labour market (Altbach, 1999).

Higher education institutions are facing a growing encroachment on their autonomy, by being required to prove their value (Harvey, 2000). In the UK, employability indicators have been set down politically to measure the performance for higher education institutions – most however have been focusing on ensuring students a job (Knight & Yorke, 2013). Second, higher education systems become more significant to a wider range of social, political, and economic activities; and thus various stakeholders are interested in controlling the competences that students gain from their studies (Trow, 2007).

The labour market has been encountering significant changes through the last twenty years – with both occupational structures with less predictable careers tracks (Heery & Salmon, 2002), job positions that are open to candidates with various profiles (Moreau & Leathwood, 2006) and long-tenure career as a relic of the past (Brown, Hesketh, & Wiliams, 2003).

The above challenges have led to the emergence of scholarly research in students' employability. Nevertheless, few studies have been conducted within the field of science education. Science study programmes appear, at first glance, as containing a well-defined focus that leads students to a clear career (Hooley, Hutchinson & Neary, 2012) with no fear of unemployment (Basle, Dubois, & Dubois, 2013). But, at second glance, it turns out that employers, within these areas, call for future students to be more orientated towards the job-market. Science students are required to have a sense of the applicability of their competences that will not require long 'learning curves' when they encounter their first employment (Mason, Williams, & Cranmer, 2009). A report from the Danish Association of Masters and PhDs shows how only 46 % feel they have achieved the right competences to manage their new job (2012). The reports indicate that a large proportion of students find their new job to be somewhat incompatible with their academic competences.

It seems crucial that science education in general and chemistry education in particular has a response to in which way it contributes to higher education students' employability. However to gain a clearer understanding of employability and to discuss the scope of its merit to a pedagogical context, we must analyse what employability is; its genealogy as well as the discourses embedded in within it. Finally we must consider the pros and cons in adapting the notion in an educational context at all. The next section provides such an analysis of the concept as an input for a discussion.

The genealogy of employability

Employability is a notion that is heavily embedded in the historical and cultural development of the society, which produces different meanings of what employability is and how it should be used. This section will portray the plateaus in the history of employability and decipher the different meanings embedded in the notions throughout the historical phases it has encountered. The development can roughly be categorized into three waves (Gazier, 1998a).

The concept of employability first appeared a century ago (Gazier, 1998b). Here the meaning of employability was those who were *willing* and *able* to work and those who were not. Employability was perceived as a tool of *diversion* of the workforce. As such, being employable was a question of the individuals' health and habits – e.g. being sober at work – but also motivation and mind-set.

The second wave appeared in 1950s and 1960s. Here employability was used to label and identify and *measure the distance* between the individual and the labour market. In particular, the focus was on the social, physical or mental *deficits* of individuals that made them unfit for employment (McGrath, 2009). Hereunder disadvantaged groups and the abilities they lacked to gain a job. Through the 1960s, fluctuations in the labour market produced an extended understanding of the notion acknowledging that employability also had to do with the probability for a person to find a job.

Finally the human resources approach appearing in the late 1980s introduced an approach to employability as *career development* in a labour market characterized by constant changes demanding of the workforce to be flexible (Gazier, 2001). Now employability is connoted to the capacity of individuals and perceived as the individual's own responsibility and interest in *optimizing personal competences*. We perceive this evolution of the concept as cultural embedded in the general development in society where todays' individuals in various areas are expected to *govern themselves* instead of being controlled by external demands.

> The individual is to become, as it were, an entrepreneur of itself, seeking to maximize its own powers, its own happiness, its own quality of life, through enhancing its autonomy and then instrumentalizing its autonomous choices in the service of its life-style. (Rose, 1998, p. 21)

An illustration of the phenomena is the balance between work life and family life, which is perceived as primarily being a challenge of each individual. Each employee in the knowledge society is required to find her own way of making sense of and balancing the challenging relation as long as it is done in way that is recognized as profitable by the employers (Kossek & Lambert, 2012).

Employability is no longer an instrument to get people into work, or a tool to measure the deficits of the employee, but an instrument to *support* the employee to develop herself in a favourable way, which is recognised as attractive by the labour market. The Foucauldian notion of governmentality can be used to understand this progress of the concept of employability. Governmentality describes a historically change in the way power exerted over the individual, from being an open external control and exercise of power, to a situation where the individual incorporates the power and exercise it on themselves (Foucault, 1997a, 1997b). As such it is the individuals own interest to become employable and their responsibility to develop themselves in a way that is demanded and perceived to be attractive by their employers. However, as we will show this discourse of employability is today facing competing discourses, that negotiates the way that meaning is ascribed to the notion. The next session will present some of those meanings that are embedded in employability today.

The different meanings embedded in employability

Employability is a difficult notion to define clearly. It is like a piece of soap between wet hands. Thus, we are interested in how different meanings of the concept of employability produce social techniques and discursive influences, which set the scene for higher education thinking in particular ways.

In society in general, and by the government in particular, employability is used as an indicator of an individual's chance of employment. From the point of view of the employer, employability is perceived as an indicator of meeting the supply and demand of the labour market. From the point of view of the individual, employability is an indicator of gaining an attractive career (Forrier & Sels, 2003).

Also within research, a range of different meanings are embedded in the concept. Recent definitions of employability have tended to focus on the abilities of the individual – labelled as *internal employability* (Forrier & Sels, 2003) – 'a set of achievements – skills, understandings and personal attributes – that makes graduates more likely to gain employment and be successful in their chosen occupations, which benefits themselves, the workforce, the community and the economy' (Yorke, 2006). Another perception of employability is *external employability:* factors of the labour market, socio-economic variables or within-organisation factors that effects the employment situation. An example is how the level of unemployment interacts with what is considered to be employability. Another definition has been in between employability as embedded in content-related competences or generic competences. It has been argued that a more sustainable employability must be achieved through ensuring that students' gain more stable generic competences. These can be embedded in curricular as well as extra-curricular activities (Watts, 2006).

As the concept of employability is brought into higher education, a range of challenges arises. One of the major concerns has been how the purpose of higher education to promote wisdom and knowledge conflict with the logic of the labour market and hence the interest in accumulating value. Therefore it is not a simple task to bring employability into chemistry education. First, the competences required in a job might be context-specific and hard to learn in an educational context (Lave & Wenger, 1991). Second, the teaching institutions and the industries are driven by different motives, which means that the students may find it difficult to transform their competences (Hennemann & Liefner, 2010); i.e. even if they learn how to manage – e.g. a chemical waste project – during their studies, managing a project in real life industries might be different. Finally, the students do not approach the labour market in uniformed ways (Fugate, Kinicki, & Ashforth, 2004), which requires universities to include various ways of fostering employability.

We will now turn to a discussion of how these challenges can be met within chemistry education.

MOVING BEYOND THE BUZZWORDS

At the outset, it seems clear that both innovation and employability have gone through a certain degree of economisation in the sense that both terms are widely used in a profit-oriented discourse about the purpose of education. In particular, both concepts have played a key role in the post-industrial notion of 'entrepreneurial universities' in which universities, beyond teaching and research, have an obligation to contribute to the economy (Martin & Etzkowitz, 2000). As such, some scholars have argued that the concepts may often connote a relatively new form of hegemony in which stakeholders outside the educational system (predominantly policymakers and industry representatives) increasingly get to dictate the aims and content of education (Martinsen, 2013).

In the above genealogies, we have attempted to point out how the semantics of the two concepts is much more complex than the economised versions educators are likely to encounter. We want to claim that it is necessary to arrive at a definition of innovation and employability, which can have a meaning at the level of pedagogy, rather than at the level of organisational or domestic strategy. In fact, we want to insist that educators can use innovation and employability proactively as pedagogical approaches when designing, implementing and evaluating their teaching. In order to flesh out this argument, we will begin by considering the commonalities between innovation and employability in terms of the pedagogical space they may span out. More concretely, we want to present, in sketch form, pedagogical approaches that may foster innovation and/or employability. Against this background, we will point to how this pedagogical space can address the three challenges for chemistry education that were raised in the introduction.

Prototypical pedagogical approaches

Based on the genealogical analysis, we hypothesise that it makes sense to speak of prototypical pedagogical approaches that can be used to address innovation and/or employability. At the very least we would imagine that pedagogical approaches that seek to foster students' innovation competency could be teaching/learning activities in which students in relative autonomy work with authentic issues from existing practices in the world. Further that the primary modus of working in such activities would amount to (a) students creatively generating solutions to these issues, while drawing on their chemistry knowledge and their analysis of the practice; (b) analyse and reflect on the value-creating potential and realizability of their ideas; (c) work towards implementing their ideas; and (d) communicate about their ideas to various stakeholders. For example, we could think of an activity in which upper secondary or university students work with a biotech company that produces enzymes for house hold products on the issue about how to rid liquid detergents from the high water content. In this hypothetical activity, students could be assigned by the company to present a portfolio of solutions to a board of representatives, who will assess the suggestions *together with the teacher* in order to evaluate not just students' disciplinary knowledge of enzymes and their production and applications but their innovation competencies (as discussed above) – specifically with regard to the realizability, utility, and potential value-creation in the practice of house hold laundering. Again, the pedagogical approaches that can be used to foster innovation may not necessarily be teaching/learning activities that are fundamentally different from the chemistry teaching we witness today. Possibly innovation competence can be fostered even through small shifts in foci in more traditional teaching/learning activities.

Employability can be incorporated into the curriculum in a range of ways: It can be incorporated through planned collaboration with external actors as suggested above but also and more importantly it can be addressed through everyday practices in upper secondary school and at the university. The latter was evident in a recent evaluation of a regional development project that seeks to reorganise teaching in upper secondary school in Denmark with a focus on foster new innovation competences. It was found that students who primarily learn in a project oriented fashion in all disciplines in upper secondary school to a notable degree were much more reflective (than students who experience teacher-centred teaching) about what they can use their gained competences for (Nielsen, 2014a).

From being implicitly embedded in the curriculum, employability must be reached through learning processes that depart from core academic knowledge and is included in the assessment as intended learning outcomes. Learning activities that support student employability will be quite similar to the ones that seek to foster innovation and to recommended higher education learning activities in general. In particular, activities that seek to foster employability would be activities in which the student is required to apply meta-reflection of learning (learning how to learn), practice transferability of knowledge, adjust and adapt to different learning situations (for example by using the right amount of effort and or by applying a suitable strategy), learn self-management and be able to work independently as well as in groups to highlight the ones we find to most crucial (Knight & Yorke, 2013).

Some of these aspects, in turn, would also be expected to be part of pedagogical approaches that seek to foster innovation competency, because engaging in innovation processes about authentic issues would often entail the need for meta-reflection – e.g. when students need to reflect on what she needs to know or be able to do, or how she has to acquires new knowledge or skills, in order to implement a given idea or suggested solution.

It should be clear already at this point, that the prototypical pedagogical foci that seek to foster innovation resemble familiar educational notions. First, there is a clear link to the idea of *problem-oriented project work* (Ulriksen, 1999) in which students work on authentic issues from existing practices in the world and put to use both their previous knowledge and abilities and the knowledge and abilities that is necessary to acquire in the process. Second, many traits of the prototypical activities that we entertain here fit well with the growing body of literature concerning *inquiry-based science teaching* in which students raise questions, engage in reasoning, search for relevant information, observe phenomena or processes, make conjectures, gather and interpret data, collaboratively discuss and work with authentic issues (Anderson, 2002). To be sure, the approaches of problem-oriented project work and inquiry teaching as well as the activities that seek to foster innovation and/or employability are all centred on the student putting to use her previous knowledge and skills and acquiring new knowledge and skills when working with issues from real-life practices. Importantly, the disciplinary content is framed or selectively chosen insofar it is relevant to the thematisation of the given issue; the disciplinary and generic skills at play in the process are initiated and monitored not just by the teacher, but also by the student; and the teachers takes on the role of guide or advisor rather than that of a lecturer.

But prototypical pedagogical approaches that foster innovation and/or employability go beyond such problem-oriented project work and inquiry teaching, because teaching for innovation and/or employability implies that the students' ideas or work are not just assessed from a disciplinary perspective, but also against the yardstick of the practice-in-reality that they are about (at least when letting students work in innovation processes). While this is possible in both problem-oriented project work and inquiry teaching, it is probably not always the case in practice.

Ameliorating the three challenges for chemistry education

Based on this characteristic of pedagogical approaches for chemistry teaching that seek to foster innovation and/or employability, we would argue that using such approaches deliberately in chemistry education – at both upper secondary and tertiary levels – may be useful from the perspective of students' teaching and learning. In other words, insofar as we rid innovation and employability from the economised connotations and begin to operationalize these concepts in a meaningful way on the level of pedagogy, we think it is possible to ameliorate the three challenges for higher education chemistry outlined in the introduction.

The first challenge concerns the balance between fostering widening participation for a range of students and supporting students who are recognised as particular talented. The second challenge concerned the discrepancy between teaching and learning in chemistry education and what we know works from a teaching/learning perspective. We wish to suggest that some pedagogical approaches can meet both challenges and at the same time enhance innovation and employability within chemistry education. The pedagogical focus on fostering students' innovation competence and/or employability implies, as argued above, a focus on facilitation student centred learning in a fundamental way that could work towards ameliorating the first two challenges.

Thus we point to student centred learning as a way to meet the first two challenges. Learning is much more complex than merely listening, memorizing and reproducing knowledge which of historical reasons has become a large part of higher education teaching. If we wish to support student learning we must begin by taking the point of departure in the students' learning processes and then adapt our teaching to support this process (Eilks & Byers, 2010). Such a focus is not to be confused with neglecting fundamental science for the sake of students' motivation and interest. Rather, we suggest that a first step is to teach fundamental science for a purpose, and, when appropriate, use practical problems as a point of departure to engage the curiosity of students (Whitesides & Deutch, 2011). We know how students who encounter higher education science struggle to see the relevance and purpose of the teaching they meet (Becker, 2010; Holmegaard, Madsen & Ulriksen, 2012; 2013; Johannsen et al., 2013). By talking about student centred learning we do not argue for self-directed learning. Instead, taking outset in the work of O'Neill and McMahan (2005) we point to following approaches:

- Active learning rather than passively absorbing knowledge,
- An emphasis on deep learning and understanding,
- An increased sense of autonomy in the learner that support the student in governing herself,
- A reflexive approach to the learning process, and
- The teacher becomes a facilitator and resource person.

More concretely, we recommend that students have a co-influence and that they have opportunity to participate in the curriculum in various ways. This can be done in various ways. For example by inviting students to decide a particular topic they want to engage with or a project they want to carry out. If we invite students to have a voice and a choice we support their interest, support relevance and to various degrees their self-management. These thoughts are not new and student centred learning has been a topic for at least 60 years (McKeachie, 1954). But it's relevance in higher education faces a revival as more students with various backgrounds, interests, and intentions enrol into higher education. Adopting a focus in fostering students' innovation competence and employability can serve as such a revival.

Further, implicitly in the first two challenges lies an issue about relevance. As student populations become more diverse, and as we face more students who are not intrinsically interested in chemistry, it becomes increasingly important to frame the disciplinary content in a way that makes transparent the relevance of the content (for a discussion of 'relevance' of content see Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013). We believe that a pedagogical focus on fostering students' innovation competence and employability necessarily entails a focus on making the teaching/learning activities relevant.

Of course, we know that changing the curriculum is not an easy task since it is part of a cultural discourse, produced and reproduced by both students and academic staff. Stiwne and Bergeling (2011) provide an example of this from Sweden, where a public discourse on 'back to basics', discipline, hard work and solid knowledge, conflicts with other aims of educating engineers as innovative, creative, sustainable and democratic citizens, who can communicate, negotiate and collaborate in a diverse, global society.

The third challenge addressed in the introduction concerns the transferability of chemistry competences from a higher education context to the job marked. A large amount of researchers have documented the problems related to transfer learning from one context to another (Yamnill & McLean, 2001). Ameliorating the challenge of transferability of higher education, we think, is a shared responsibility between higher education and the labour market. Our hypothesis is, that a pedagogical focus on fostering students' innovation competence and employability could result in different forms of collaboration between actors in the labour market and schools/universities. This could either happen as parts of the curriculum – i.e. that students in some courses work together with companies or other stakeholders – or in parallel to the curriculum – i.e. that the university facilitates student-industry collaborations that are seen as auxiliary to the coursework (Yorke, 2006).

Beyond this, we claim that a pedagogical focus on fostering students' innovation competence and employability will entail a focus on transfer on an even more fundamental level. It is widely acknowledge that there is a number of ways to address the issue of transferability – such as facilitating that students learn to understand the underlying principles of the skills they acquire, that students are allowed to work in several different contexts or situations, that students are allowed to work in new ways with issues, that students are allowed to discursively reflect on their learning, and that students are encouraged to apply what they have learned in novel contexts and on new issues (Goldstein, 1986; Yamnill & McLean, 2001). Again, as we have argued above, all these ways of addressing transfer ought to be a natural part of having a pedagogical focus on fostering students' innovation competence and employability.

CONCLUSION

In this chapter we have argued that chemistry education, in particular at the level of higher education, faces at least three challenges. By tracing back the genealogies of the concepts of innovation and employability, we have identified a way to understand these two concepts in a way that rids them off the current economic connotations and which renders their usage meaningful at the level of pedagogy. We have then sketched what we perceive to be the fundamental traits of a pedagogical focus on fostering students' innovation competence and employability. Finally we have argued that this focus, in principle, can be a way to ameliorate the three challenges.

Thus, we have argued that chemistry teaching that focuses on fostering employability or facilitate innovative processes on the side of the students can become relevant for a number of reasons. The idea that chemistry teaching activities can lead to some concrete new creations that are valuable to someone has immense potential. The same is true for chemistry teaching activities that focus on strengthening the employability of students in the form of increasing their meta-reflection and flexibility vis-à-vis applying their competences or acquiring new knowledge and skills. Clearly, when students work on issues in the ways proposed here has the potential to make the related chemistry learning relevant for the students (a quality that is in high demand; e.g. EU-Commission, 2004). Further, the notion that students work on real issues and that their solutions should have an actual value for someone could be seen as a exemplary versions of types of learning that are presently heralded – e.g. discovery learning, inquiry learning, or more generally, problem-based learning. Essentially, we think that a pedagogical focus on fostering students' innovation competence and employability resonates neatly with Gibbons' (1997) ideas of knowledge production in the 21st century: The idea that knowledge is increasingly "*transdisciplinary*" and that it is "*worked out in the context of application*" (p. 3).

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18. RELEVANCE OF NON-FORMAL EDUCATION IN SCIENCE EDUCATION

Non-formal education is a relevant part of meaningful and holistic science education. This chapter describes three programs in science, mathematics and technology education organized by the LUMA (STEM) Centre Finland. These successful programs are research-based and designed to (I) motivate children and youth towards STEM-subjects, (II) help them to learn new skills, and (III) be relevant to the students' lives. The examples described are: 1) the Little Jippos Science Clubs aimed at 3-6 year olds, 2) the innovative chemistry learning environment Chemistry Lab Gadolin aimed at 7-19 year olds, and 3) the international Millennium Youth Camp aimed at gifted 16-19 year olds. This chapter will discuss how these examples can contribute to relevant science education. Some suggestions are also given regarding why they are able to support children and youth in ways that formal education typically is not. This chapter will also describe how different forms of non-formal education may be used to address the different areas of relevance, and how a system of non-formal educational programs should be built to address all the areas of relevant science education.

INTRODUCTION

In the past decade there have been numerous studies that have indicated that mathematics and science education is unpopular among youth (Osborne, Simon, & Collins, 2003). Researchers believe that one of the reasons behind this is that the youth often see science education as irrelevant to their everyday lives and to society (Gilbert, 2006). As a result, curriculum developers have begun to emphasize the importance of non-formal education in order to raise the interest and motivation of youth and children (e.g. Shohel & Howes, 2011). However, as Stuckey, Hofstein, Mamlok-Naaman, and Eilks (2013) discussed, relevant education is not only about raising interest and motivation, but it should also have a broader individual, as well as a societal and vocational dimension. Furthermore, they conclude that education should be relevant today and in the future, and that the relevance may be intrinsic or extrinsic. In this chapter we will look at how non-formal education can meet the needs of relevance by looking at three cases of meaningful non-formal science education organized by the LUMA Centre Finland.

LUMA Centre Finland (LU stands for 'luonnontieteet', or natural sciences in Finnish, and MA stands for mathematics) is the umbrella organization for national

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and international LUMA operations within the network of twelve LUMA Centres in Finnish universities. The LUMA Centre helps schools, universities and the business sector to collaborate with each other in order to promote and support life-long learning, as well as the studying and teaching STEM subjects at all levels of education (LUMA Centre, 2014). There are many different kinds of non-formal education activities being conducted in Finland, including various camps, interactive clubs and webzines, such as the Little Jippos club for children as well as the Luova and MyScience webzines for youth. The LUMA Centre also supports in-service teachers through in-service training and webzines aimed at teachers, such as the LUMA News.

FORMAL AND NON-FORMAL EDUCATION

In the 1960s the need to respond to new educational demands began to grow, particularly regarding those students who did not have the opportunity to attend formal education (Belle, 1982). Due to these needs, different kinds of educational programs emerged, which were commonly referred to as non-formal education (Belle, 1982). Since then, the scope of non-formal education has expanded and today the term is used to refer to any out-of-school education, including science camps, enrichments programs, and voluntary online projects that follow a specific program and are often visited by a group of students. In comparison, private visits to museums, zoos, etc. are typically referred to as informal education (see Chapter 19 of Coll and Treagust in this book).

Therefore, non-formal education may closely resemble formal education, but certain distinctions between the two exist. The greatest difference is that non-formal education is usually not tied to a national curriculum (Eshach, 2007), giving non-formal education more freedom to teach what educators find to be relevant to a particular, often selected, group of students (Hofstein & Rosenfeld, 1995). Non-formal education can offer many kinds of possibilities, including the ability (I) to teach multidisciplinary fields such as sustainable development, (II) to use new teaching methods, which is not necessarily possible during school days, or to try new kinds of collaboration (e.g., with parents or businesses) or (III) to offer students new kinds of projects that they have been wishing for. Due to this freedom from curricula, non-formal education is usually not evaluated and it is voluntary for the students (Eshach, 2007). Furthermore, non-formal learning is arranged outside of school hours and usually takes place somewhere outside of school facilities (Eshach, 2007). The lessons are also often longer than lessons in formal education.

Due to these distinctions, non-formal education has been found to have many benefits both academically and socially. For instance, Pedretti (2002) found that non-formal education can be beneficial to attitudes and motivation of students. In his findings, he noted that visits of classes to science centers sparked a sense of wonder and interest towards science education among the students. In addition, non-formal education can give students self-confidence not only in their studies, but also regarding their future careers (Tolppanen & Aksela, 2013). Furthermore, these changes in attitude may persist over time (Tolppanen & Aksela, 2013) and the boost in motivation may help students engage in science activities later on in life (Germann, 1988). In a 4-year longitudinal study, it was noted that participants in non-formal education experienced an increase in interest towards learning (Thomas, 1989).

In addition to academic benefits, non-formal education gives the opportunity to interact with other students who share common interests and helps them find role models in the fields they are interested in (Tolppanen & Aksela, 2013). In fact, the social surroundings and the support of teachers and experts seem to be important factors affecting motivation (Tannenbaum, 1983), as students usually begin to see their potential in social interaction with others. Furthermore, interacting with other students and teachers over issues that require reflection and interpretation of experiences may help in constructing knowledge (Rahm, 2004).

CASES ON NON-FORMAL SCIENCE LEARNING AT THE LUMA CENTRE IN FINLAND

This chapter intends to assess three non-formal education programs organized by the LUMA Centre Finland concerning their contribution to relevant science education. These programs are aimed at students of different ages: (i) Little Jippos clubs aimed at 3-6 year olds, (ii) ChemistryLab Gadolin aimed at 7-19 year olds and (iii) the international Millennium Youth Camp aimed at gifted 16-19 year olds. By assessing these three programs, this chapter aims to answer the question: *How can non-formal education contribute to relevant science education?*

By answering this question we aim to discuss how non-formal education should have continuity from age group to age group in order to best meet all three dimensions of relevant science education.

The relevance of non-formal science learning to 3–6 year old children

This section discusses the relevance of a non-formal learning environment (the Little Jippos club) aimed at 3-6 year old children. We begin by arguing why science education should begin at an early stage with children as young as three years old. Subsequently, the learning environment and its core features are described. This section concludes with an analysis of the core features of the non-formal learning environment for 3-6 year olds from the perspective of the proposed model of relevance in science education by Stuckey et al. (2013).

Background. Human beings have an innate motivation to study the world around them. Independent of adults, children become familiar with their surroundings by exploring, observing, and making conclusions. Science education should be provided for children from a very early age to ensure that their perceptions of the way the environment functions are heading into the right direction (Eshach & Fried, 2005).

Children are most eager to ask questions related to cause-effect relationships when they are 4-6 years old. The responses they receive are a powerful way for them to build their vocabulary. Science education should begin during this sensitive period of language development when children are ready to absorb correct expressions and concepts related to scientific tools and phenomena. Language has a significant impact on how concepts are constructed. Early absorption of scientifically sound expressions has a positive effect on the learning of scientific concepts in later education (Eshach & Fried, 2005).

Learning is always connected to emotions related to prior learning events. If children feel that science content is important to them and if the learning is enjoyable, it is likely that the sparked interest in science will also be retained into the future (Ainley & Ainley, 2011). For this reason, it is important to develop science learning environments for small children where the significance of enjoyment to science learning and motivation are taken into account. Students' perceptions of their own abilities and skills in science affect their academic performance and study paths. When children are allowed to participate in inquiry-based science learning, it increases their feelings of enjoyment and excitement towards science, as well as their feeling of competence (Mantzicopoulos, Patrick, & Samarapungavan, 2008.)

At the kindergarten and pre-school levels, science education is embedded into curricula in such countries as Finland, Germany, and the UK. In Finland, 30-40% of children between ages 1-6 are not involved in formal education (THL, 2013). It is therefore essential that there are also professional non-formal education options that are available to every child, whether they are in kindergarten or at home.

The Little Jippos Learning Environment. The LUMA (STEM) Centre Finland has been successful in providing science education environments for children and families (Vartiainen & Aksela, 2012). In 2013, a science education program for 3-6 year old children was launched at the University of Helsinki (Vartiainen & Aksela, 2013). One of the main functions of this program is a science club for children. A science club is a non-formal learning environment where students have access to resources with which they may develop their understanding and come up with sensible solutions to problems

The curriculum of the Little Jippos STEM club was planned based on design research to meet the following goals:

- To support children's interest in mathematics, science and technology through holistic education with a special focus on the emotions related to their learning,
- To support children's learning of science process skills,
- To encourage children to wonder about every day phenomena and to ask questions about the surrounding world,
- To make experiments enjoyable through arts, stories, play, positive feelings, and social interaction, and
- To give parents tools to support the science hobby of their children.

The Little Jippos science club has been organized at the Faculty of Science of the University of Helsinki. The purpose of choosing the university environment as the location was to show children and their parents what an authentic science environment looks like to make the academic world and the people who work there less mysterious and easier to approach. Club meetings have been held in a classroom refitted for the purposes of children education. Tables and chairs have been moved to the sides of the classroom to make an open area for sitting on the floor in a big circle for motivation and conclusion conversations. Some tables have been used to build secret caves where experiments are carried out in small groups.

The Little Jippos club points out the social perspective of a learning environment. During club meetings children interact with issues related to science with three instructors and with other children. The club meetings contain discussions with the entire group and close interaction in small groups. The level of discussion varies from describing the children's everyday experiences in scientific terms to planning experiments, discussing observations, and comparing results.

A fictional story is used to tie all six club meetings together as a whole. This fictional frame creates a role-play within the club: children are in fact the researchers who are assigned tasks by a professor who lives in outer space. The themes of the club are directly related to everyday events and phenomena in the children's lives, such as the melting of snow, forming of rainbows, and flotation of objects. The children are allowed to operatively study the natural phenomena related to the chosen themes. Explorations are performed in small-groups of three or four children and one instructor. The inquiry-based approach gives children the opportunity to use tools and methods that are appropriate for their developmental level (Sackes, Trundle, & Flevares, 2009). As researchers, children need to observe, ask questions, collect data and make predictions with the guidance of the instructor to solve the given task. The purpose is to create a foundation for understanding that the production of scientific knowledge is a communal process and to dispel alternative notions about science being magical or dangerous (Mantzicopoulos et al., 2008). Inquiry-based learning also supports the development of the children's science process skills. These skills are necessary in all fields of science. They form the basis for learning scientific thinking. The learning of science process skills begins in early childhood and develops in stages as children age (Kuhn & Pearsall, 2000).

The children also receive an open ended exploration task as homework after every club meeting. The homework assignment is to be completed with parents, grandparents, older siblings or other persons close to the child. The purpose of the homework assignment is to involve the parents and other family members into the science hobby of the child and gives them tips on how they can conduct their own science experiments related to everyday phenomena with the child with tools and materials they have at home. The children also ask their parents, and other close adults, questions about nature and natural phenomena. When children are able to discuss their observations with their parents, it also helps them to learn scientific thinking (Crowley et al., 2001). Little Jippos supports parents in discussing scientific matters with their child. It has been observed that the attitudes of guardians have a remarkable effect on the interest development of children (Chak, 2010). However, there is room for improvement in the parents' knowledge of the possible future career opportunities that science offers their child (Hill & Tyson, 2009). For this reason it is important to also familiarize the parents with the world of science and help them understand its societal significance so that they can better support their child in future education and career choices.

To summarize, the nine main features of the Little Jippos science club are:

- Location at the University of Helsinki Science Campus,
- Peer interaction and interaction with adult instructors during club meetings,
- Support for the family and committing them to the science education of their child,
- Role-play (children play researchers),
- Child's personal environment as a starting point for experiments,
- Stories that motivate the activities and tie the children's previous observations and notions about natural phenomena to the learning event,
- Art as a tool for expressing the results of experiments,
- Emphasis on positive emotions towards scientific content and learning, and
- Training of intellectual and transferable science process skills.

The relevance of the main features of the Little Jippos learning environment. In order to determine the relevance of the Little Jippos learning environment, the nine main features of the club were classified according to the three dimensions of relevance (Stuckey et al., 2013). The classification was made by two researchers. The guiding principle was to place each feature of the Little Jippos curriculum into one of the three dimensions of relevance: 1) individual, 2) societal, and 3) vocational. Each feature could only be classified into one category. After this classification was conducted, the results were compared and discussed.

Out of the nine main features, seven were classified into the same dimension of relevance by the two researchers. The classification of the features is presented in Table 1. The views of the researchers differed in the classification of two features, namely 3) support for the family and committing them to the science education of their child and 4) roleplay (children play researchers). The discussion after the classification revealed that both researchers agreed that feature 4 could have been placed in all three dimensions. Feature 3 could be interpreted either from the perspective of the child or the parent, which caused the difference in the categorization between the two researchers. The dimensions of relevance are not necessarily separate from each other, but instead they are connected and overlapping (Stuckey et al., 2013).

The inter-rater reliability (ir) index of the classifications made by the two researchers was found to be reasonable (ir = 0.78). The index was based on the percentage agreement level of the two researchers.

Table 1. Researchers' views on categorizing the features into the three domains of relevance

Feature		Researcher 1	Researcher 2
1)	Location at the University of Helsinki Science Campus	Vocational	Vocational
2)	Peer interaction and interaction with adult instructors during club meetings	Societal	Societal
3)	Support for the family and committing them to the science education of their child	Vocational	Individual
4)	Roleplay: children play researchers	Societal	Vocational
5)	Child's personal environment as a starting point for experiments	Individual	Individual
6)	Stories that motivate the activities and tie the children's previous observations and notions about natural phenomena to the learning event	Individual	Individual
7)	Art as a tool for expressing the results of experiments	Individual	Individual
8)	Emphasis on positive emotions regarding science content and learning	Individual	Individual
9)	Training of intellectual and transferable science process skills	Vocational	Vocational

The Little Jippos learning environment is most supportive to the individual dimension of relevance. For small children, this is the recommended emphasis (Newton, 1988). The central features of Little Jippos that were found to be most essential to individual relevance were features 5, 6, 7 and 8. Connecting science education to the everyday life of the learner is perceived to be important for relevance (De Jong, 2006). The themes of the Little Jippos learning environment are all picked from phenomena children come across in their everyday lives. Stories are an effective way of involving the personal world of children in education. Stories encourage children to discuss reflectively and debate constructively (Sackes, Trundle, & Flevares, 2009). There are skills all children will need in all areas of life in the future. Adult support plays a significant role in the development of the scientific self-efficacy of children (Haynes, Ben-Avie, & Ensign, 2003). In the Little Jippos learning environment, the childrens' positive feelings are emphasized and their interest in science is bolstered. Furthermore, as children tend to enjoy making art, the inclusion of drawing, painting and modelling in science experiments has a positive effect on their enjoyment.

The societal dimension of relevance is the least emphasized aspect of relevance in the Little Jippos non-formal learning environment. This is natural when the age of the children is taken into account (Newton, 1988). The Little Jippos club emphasizes practicing versatile social interaction and discussion about science. One of the main features of the club that was perceived to belong to the societal dimension of relevance was 2) peer interaction and interaction with adult instructors during club meetings. The purpose of this feature is to teach children the rules of proper social interaction and to provide them with tools that they need to be able to function in society. The other feature of Little Jippos that was considered to belong to the societal dimension was 4) roleplay (children play researchers), where children are given the opportunity to produce scientific information at a basic level. Inquiry-based learning where children operate as simplified researchers helps them understand how scientific knowledge is constructed (Mantzicopoulos et al., 2008). In the Little Jippos learning environment this inquiry-based learning activity is emphasized with roleplaying.

Relevant science education should prepare children for future studies and career planning (Young & Glanfield, 1998). Factors that support these goals may be seen to belong to the vocational dimension of relevance. One of the main features of Little Jippos was found to belong to this dimension: 1) location at the University of Helsinki Science Campus. This location allows children to personally experience a university building and see the people who work there.

The attitudes of parents have a significant effect on the future study and career paths of children (Chak, 2010). The Little Jippos learning environment supports the interaction between parents and children in the context of science and increases the parents' knowledge of the significance of natural sciences. Increased interaction has a positive impact on the children's later science education (Harackiewicz, Rozek, Hullemann, & Hyde, 2012).

Feature 9 from Table 1 training of intellectual and transferable science process skills belongs in the vocational dimension of relevance. Science process skills are necessary for the development of scientific knowledge and for academic achievement in scientific studies later in life (Campbell, Pungello, Miller-Johnson, Burchinal, & Ramey, 2001).

The relevance of non-formal learning to 7-19 year old students

This part of the chapter focuses on the relevance of the ChemistryLab Gadolin, a non-formal learning environment for Finnish schools at all levels. This section begins by explaining the background, activities and learning environment of the ChemistryLab Gadolin and moves towards discussing its relevance to science education in the individual, societal, and vocational dimensions.

Background. Science education struggles with the same problem in Finland as it does elsewhere: lack of student interest (Kärnä, Hakonen, & Jorma Kuusela, 2012). ChemistryLab Gadolin is a modern learning environment that was designed to support the learner and teachers and to promote the importance of society, working life and the chemical industry in chemistry education. The basic principles of Gadolin are based on the Finnish national curricula and research in chemistry education. Furthermore, Gadolin aims to promote the positive image of chemistry, with a special focus on pointing out the ways in which chemistry can help to develop the world, encouraging students to study chemistry at all levels, and supporting teachers in meaningful learning.

ChemistryLab Gadolin is a collaboratively built project between the University of Helsinki, the chemical industry, laboratory instrument manufacturers, education councils, and schools at all levels of education in Finland. The list of partners includes the Department of Chemistry of the University of Helsinki, the Faculty of Pharmacy of the University of Helsinki, the Chemical Industry Federation of Finland and many global companies (e.g., Kemira, Neste Oil, UPM-Kymmene, AGA, BASF, Borealis Polymers, and Bruker Corporation). The industry is also an active partner in the Gadolin steering group. Several companies also offer materials and modern instruments for the use in Gadolin (e.g., Epicur Group, IS-Vet, Laskentaväline, Metrohm Nordic, Miliot Science, PLD Finland, 3M, Thermo Fisher Scientific, and VWR International).

The laboratory is situated in the Department of Chemistry in the University of Helsinki and it was launched in the fall of 2008. By the end of 2013 more than 15.000 Finnish children, youth and teachers have taken part in Gadolin activities, all of which are free of charge. In addition, educators and policy makers from around the world have been keen to see the Gadolin model.

Activities. Context-based learning, laboratory activities and study visits increase interest and produce a better understanding of science (Hofstein & Kesner, 2006). There have been plenty of context-based chemistry projects that have yielded positive results aboard, including the Salters' Chemistry curricula in the United Kingdom and other countries (Bennett & Lubben, 2006), or Industrial Chemistry in Israel (Hofstein & Kesner, 2006), to mention a few.

ChemistryLab Gadolin brings all its partners together to create a context-based learning environment that focuses on the contextual connections between Science-Technology-Society (STS). The main contexts in Gadolin are everyday chemistry, green chemistry, material chemistry, sustainable development, and health and wellbeing. Gadolin also collaborates with specialists in chemistry teacher education by conducting education research and pre-service and in-service training for teachers.

On a daily basis, Gadolin organizes opportunities for school students to enjoy chemistry through learning by conducting experiments, participating in chemistry-related activities or meeting scientists at the different departments of the University of Helsinki. Each visit is designed together with the students' teacher, so the visits will deal with the same content as the teacher is teaching in school at the moment. The teacher may choose from activities such as laboratory work, molecular modelling, meeting scientists at the department, seminars about studying chemistry or working in the field of chemistry, and campus sightseeing to other science departments (physics, mathematics, geography, or meteorology). Each visit lasts 1-8 hours. Gadolin also organizes camps, clubs, birthday parties, workshops, demo-shows and visits to industry. In all, the offered program consists of over 50 activities conducted either in the Gadolin laboratory or at school. It also educates teachers (in- and pre-service training) in new teaching methods in modern chemistry (e.g., workshops, courses, and webinars).

Much of the materials have been developed by specialists from industry or research units. Some of the material is produced in collaboration with pre-service chemistry teachers and chemical industry partners. Specialists are brought in to improve laboratory sheets and bring updated ideas and methods. These activities aim to follow the guideline set by Orion and Hofstein (1994), in which students are given related activities/activities before, during and after the visit.

The operations of Gadolin are continuously developed and research plays an important role. In the context of Gadolin, research means that:

- The foundation and activities of Gadolin are based on literature and best practices,
- The activities and study material are constantly being developed and researched, and
- Educational research is conducted on student groups during their laboratory work.

Gadolin as a non-formal learning environment. As a non-formal learning environment, Gadolin grants students more time, freedom, and autonomy than formal learning. Equally important to learning the content, is that students learn inquiry skills and get familiarized with the nature of science. Fundamentally, the aim is therefore to provide activities that are relevant to the students.

In some cases, Gadolin combines elements of non-formal, informal and formal learning environments. Non-formal and in-formal learning is more present in the clubs and camps organized by Gadolin. They provide children and youth the opportunity to meet other people who are interested in science and experience mutual affection towards science activities. Study visits for school groups combine formal and non-formal learning. The fact that each visit is structured by a teacher and is in line with the school curriculum is the formal aspect of a study visit. In this sense, the study visit is part of the chemistry course and the same concept that could be learned in the classroom is learned in an environment outside of school.

Relevant science education in ChemistryLab Gadolin. The easiest way to observe relevance and its three dimensions (individual, societal, and vocational) in Gadolin is to look at the contexts, different study environments, and hands-on work conducted in Gadolin. All the activities at Gadolin are tied to the context of everyday life, which promotes the relevance of learning science. The greatest strength of Gadolin is its diversity. The holistic view on everyday chemistry, society, education and the chemical industry makes for a more meaningful environment.

The individual dimension of relevance is present in Gadolin through the contextualized topics, which include the environment, kitchen chemistry, well-being, health, common materials, sustainable development, plants, soil, and water, just to name a few. The fact that the topics are closely related to everyday life increases interest towards the science activities.

Individual relevance in the present sense is about understanding the relationships between real life and science in an extrinsic way, while experiences and the fascination and interest in science are present in an intrinsic way. The motivating aspect of Gadolin activities may lead to the use of science in real life and help to motivate the students in their further science studies. For example, molecular gastronomy is a good way to introduce chemistry into a kitchen context. Molecular gastronomy shows direct links between everyday life and science.

The societal dimension of relevance may be observed through the contexts of sustainable development, used chemicals, co-operative work, and the sharing of common interests. When viewed in this sense, some Gadolin activities promote the idea of taking more responsibility of about choosing the right materials and lowering the consumption of energy in society. Hydrogen cars and industrial exhaust research are good examples of this. In a way, Gadolin also promotes environmental thinking. One Gadolin activity involves playing a customs official investigating the legality of different samples. These kinds of ideas may, for instance, encourage students and youth to join a public organization to promote sustainability or the public good.

Working in groups is the central societal aspect of Gadolin. Group work and discussion promote the sharing of ideas and values with other members of the group. Some of the visitors who have taken part in Gadolin clubs and camps plan to do so again in the future.

The vocational dimension of relevance enters Gadolin in the form of laboratory work, computational chemistry, and presentations about the vocational and academic possibilities offered by chemistry. Gadolin's connections to university research, the chemical industry, and science in general are also part of the vocational dimension.

The vocational dimension contains also the promotion of scientific knowledge and the possibilities offered by being a scientist. Meeting researchers or chemists in person or via webinars and study visits to industry locations are also important parts of the vocational dimension. On the personal level, visits to research groups and meeting scientists in person help to do away with prejudices against the stereotypical scientist.

Some of the student groups who visit Gadolin come from vocational schools. Hands-on, real life related activities and visits may increase the students' interest in science and result in better grades, if the students are motivated to become scientists. Combining society and technology in the context of sustainable development may also encourage students to promote science or the smart and sustainable development of industry in the future.

According to a study by Aksela and Pernaa (2009), Finnish teachers see the following as the most relevant aspects of Gadolin: a genuine laboratory environment, special equipment, hands-on work, professional approach to activities, creative atmosphere, researcher meetings, experiencing a university campus and information regarding the possibilities offered by chemistry. One teacher also made the interesting point that content learned at school fit well with university laboratory theory.

Non-formal education for gifted 16-19 year old students

This section will look at how a non-formal education program, the international Millennium Youth Camp, is relevant for gifted students. In the beginning, the selection process of the campers is explained, after which some of the key features of the camp are discussed. After this foundation is laid, this section will reflect on the structure of the Millennium Youth Camp with regard to the relevance of non-formal education.

Background. Gifted students have an urge to develop themselves by deepening their knowledge and reasoning skills, and by establishing peer relationships. Gifted students also tend to have clear goals they want to achieve, which can make them demanding of their education (Subotnik, Olszewski-Kubilius, & Worrell, 2011). Because of these reasons, we know from previous research that gifted education should reflect the students' passions, interests and ability by providing a curriculum that meets their needs (Subotnik et al., 2011). In addition to academic needs, the social support from peers, family and teachers is important (Tannenbaum, 1983) because if the people around gifted students devalue academic effort and achievement, so may the students themselves (Bliuc, Ellis, Goodyear, & Hendres, 2011). Furthermore, gifted students are more oriented to think about moral issues than their non-gifted peers. Their high moral concern is seen in the questions they present (Tirri, Tolppanen, Aksela, & Kuusisto, 2012). Because of these needs, non-formal education has been seen as a means to support gifted education. Previous research shows that non-formal education, such as enrichment programs, may increase a youth's motivation and self-confidence (Tolppanen & Aksela, 2013). Non-formal education also provides the possibility for an accelerated curriculum and it may be tailored to meet the interests of the youth. In this section, we deepen the discussion on what type of non-formal education curriculum can best achieve these goals of individual relevance while also discussing societal and vocational relevance.

Selection process of campers. The attendees of the Millennium Youth Camp (MYC) are gifted 16-19 year old youth from all around the world. Each year the camp has over 1.000 applicants from over a hundred countries, out of which 60 campers are selected. The selection of the campers is conducted as a rigorous, two-stage selection process.

In the first stage, applicants fill out an online survey containing open ended questions about their motivation and previous accomplishments. In the survey, applicants are also asked to select one of ten theme groups that they are most interested in. These themes are *Applied mathematics, Bioscience & technology, Climate & climate change, Energy, Food science & technology, ICT, Material science & technology, Renewable resources, Urban planning* and *Water*. Twenty applicants for each of the ten theme groups are selected for the second round of application.

In the second round of application, the applicants are assigned a project related to the theme of their interest. Applicants have one month to complete their projects, which are then assessed by experts in the given themes. The projects are ranked, and the applicants with the best projects are interviewed. Based on the collected information, experts then select six campers for each of the ten theme groups.

Structure of the camp. The Millennium Youth Camp is a one week long camp held once a year in Finland organized by the LUMA Centre, Technology Academy and Aalto University in collaboration with other partners (including global-oriented companies and organizations). The sixty campers are placed into their respective theme groups, all ten of which are related to sustainable development. All of these groups follow the general curriculum of the camp, which has the following goals:

- Encourage 16-19 year olds to study mathematics, natural sciences, and technology,
- Introduce students to the academic and professional opportunities that Finland has to offer in the areas of mathematics, natural sciences and technology, as well as help strengthen the image of Finland as a great country to come to study and work,
- Make the Millennium Technology Prize better known,
- Help the youth network with each other as well as provide them with opportunities to meet researchers and stakeholders in Finnish companies and organizations, and
- Provide the youth the opportunity to have fun with like-minded youth and enjoy their experience in Finland.

These goals are attained by the numerous academic and social activities at the camp. Academic activities include visiting universities and companies, attending the Millennium Prize Gala (held every other year), participating in the amazing race of science and visiting a science center or having a workshop with entrepreneurs. The formal social activities consist of an international evening, a sauna-night, a Helsinki tour, evening games and fun, and a welcome and farewell party (for more details, see Tolppanen & Aksela, 2013). In addition to the formal program, campers are given free time to interact with each other and the experts, and to work on a project already assigned to them before the camp.

Project work. Two months before the camp, the campers begin to work with their theme groups on an online group project assigned to them by a coach, who is an expert in the given field. Each project varies in content, but they all follow the following general curriculum:

- The projects are related to sustainable development,
- There should not be only one right answer to the research question,
- The projects should encourage students to think creatively, and
- The projects should deal with an ongoing discussion between science and society.

The coach provides the campers with reading material and helps the students with their project as new questions arise. As the campers are from all around the world, working on the project at the same time is usually not possible, so the campers are expected to contribute through online chats and blog discussions. The main goal of the project is to familiarize the students with the theme and to create new solutions to an existing problem. The projects are assigned certain checkpoints to ensure that the projects are well underway by the time the campers arrive in Finland.

During the one week camp, the campers continue working on their projects on a daily basis. Each day they have 2 to 4 hours to work on their project in the presence of their coach. At the end of the camp, the campers present their work at the Millennium Youth Camp Gala, where experts from universities and ambassadors from the campers' home countries are present.

The relevance of the Millennium Youth Camp. In order to examine the relevance of the Millennium Youth Camp, a content analysis was conducted on the camp's curriculum by two researchers who, independently from each other, categorized the nine goals of the curriculum into the three dimensions of relevance (individual, societal and vocational) presented by Stuckey et al. (2013). The researchers were asked to place each goal into only one dimension. However, if they felt that a goal had two or more distinct sub-goals within it, they were allowed to place the separate sections of the goal into different dimensions. When the researchers had individually categorized the goals, their results were compared with each other.

The two researchers had treated one of the goals (goal 4) as two separate goals (goal 4a and 4b). Therefore, there were 10 goals in total that were assessed by the researchers. In the first round of comparison, the researchers agreed on the categorization of eight out of ten goals (Table 2).

Based on the classifications of the two researchers, the inter-rater reliability was found to be reasonable (ir = 0.80).

The two goals which the researchers disagreed on were then discussed. The two researchers agreed that goals 1 and 3 in Table 2 had both societal and vocational relevance, depending on how they were analyzed. However, as further information on what was meant by the goals was not available, the researchers agreed that placing the goals in only one of the categories would be misleading. Therefore, it was agreed that these two goals belong to the categories of both societal and vocational relevance.

Individual relevance of the Millennium Youth Camp is present in the way it aims to help youth to network with each other (4a) and gives students the opportunity to have fun with like-minded students (5). Having these goals as part of a non-formal education program is important, as earlier research has shown that gifted youth find peer acceptance important (Bliuc et al., 2011).

On one hand, homogenous groups may be a positive factor, as students may be motivated by other youth who share their interests. This can lead to an increase in intrinsic motivation, through which the student may receive more motivation to aim high and achieve his or her goals.

Table 2. Researchers' views on categorizing the goals into the three domains of relevance

Goal	Researcher 1	Researcher 2
1. To study STEM subjects	Societal	Vocational
2. Introduce academic and professional opportunities	Vocational	Vocational
3. Make the Millennium Prize more well known	Societal	Vocational
4a. Help youth network with each other	Individual	Individual
4b. Help youth network with experts	Vocational	Vocational
5. Have fun with like-minded youth	Individual	Individual
6. Project on sustainable development	Societal	Societal
7. Right answer to research questions does not exist	Individual	Individual
8. Projects encourage creative thinking	Individual	Individual
9. Projects deal with issues related to science & society	Societal	Societal

On the other hand, homogenous groups may also increase competition. This can lead to an increase in extrinsic motivation, but this motivation may not last for prolonged periods of time. However, as the main focus of the Millennium Youth Camp is on group projects, competition may not be as strongly present as in non-formal programs where tasks are done individually. For this reason, a boost in intrinsic motivation is more likely. Either way, the data collected during the camp shows that students are inspired by their peers. This may be seen in one of the answers written in the feedback form collected at the end of the Millennium Youth Camp as a male participant from South-America writes: "*Working with experts and other teenagers in the field we're all passionate about will help me in my future for sure.*"

Furthermore, individual relevance exists in the projects that deal with complex, multifaceted problems, that do not have a single right answer (7). Dealing with these kinds of problems helps increase science literacy and critical thinking. In addition, the projects aim to encourage creative thinking, which is said to be one of the most important characteristics needed in work communities today and in the future.

Societal relevance is an important part of a non-formal program aimed at gifted youth, as gifted youth have the tendency to want to change the world for the better (Vesterinen, Tolppanen, & Aksela, unpublished) and are usually more inclined to think about moral issues than non-gifted youth (Narváez, 1993). At the Millennium Youth Camp societal relevance is mainly implemented through project work, in which students deal with topics related to sustainable development (6) and participate in an ongoing discussion between science and society (9).

Dealing with topics on sustainable development is important, as it is through these kinds of topics that students may learn to understand the nature of science and how scientific research is affected by society. Furthermore, through studying sustainable development, students not only focus on the science, but are also forced to look at the related societal and economic issues (Burmeister, Rauch, & Eilks, 2012). This may eventually lead them to understand the complexities of how science is affected by the needs of society and how society and economy usually decide what is researched in science. At the Millennium Youth Camp, understanding of this is developed further by encouraging students to participate in the ongoing discussion between science and society while working on and presenting their projects.

One of the great societal challenges of today is to enhance professionally enough talented scientists. By providing non-formal education which aims to encourage gifted students to study STEM subjects (1), society has a better chance of reducing the deficit of scientists. In addition, making the Millennium Prize better known (3) helps the students understand the societal importance of scientific achievements, possibly further encouraging them to pursue a career in science.

Participants in the Millennium Youth Camp are at an age where future vocation is being considered, if not yet decided. Therefore, vocational relevance for gifted youth is an important part of non-formal education. In the Millennium Youth Camp, the first goal is to encourage gifted youth to pursue a career in science, mathematics and technology (1). One way this is addressed during the camp is by demonstrating to the youth the academic possibilities that Finland has to offer them (2). Earlier research has shown that role models are an important factor when youth choose a career to pursue, so the Millennium Youth Camp aims to provide gifted youth with role models by giving them the opportunity to network with experts in different fields of science (4b). These encounters build the students' understanding of what scientists do, helping them achieve a more holistic view of the work of scientists. In addition to encountering scientists who are positioned in universities and companies, they are also provided the opportunity to witness how some of the most renowned scientists are awarded for their life's work with the Millennium Technology Prize (3). As gifted youth tend to want to change the world and be a part of something meaningful (Vesterinen et al., unpublished), understanding how important science is to society may encourage them to do so through science.

CONCLUSION

As has already been suggested in this chapter, non-formal education is relevant to students of all ages. Depending on the age of the students, different dimensions of relevance are emphasized, but regardless of age, all three dimensions may, and should, be present in non-formal education. In this last section we will sum up the relevance of non-formal education for different student groups as well as suggest what formal education can learn from non-formal education.

For very young students (3-6 years old), non-formal education is especially relevant in the individual dimension. In the Little Jippos club, the main goals are to get young students interested in science and satisfy their curiosity by giving them the opportunity to do simple and fun research tasks. Furthermore, as they learn to get along with peers and adults, they gain valuable teamwork and conversational skills for their future. In addition to the relevance for the individual, non-formal education for very young students may also have vocational relevance, such as learning to interact with scientists and being familiarized with the university environment. Through these experiences students may gain role models and realize that scientists are normal people. By bringing science closer to the lives of young students, the students have a greater chance of wanting to pursue a career in science. The societal relevance of Little Jippos is also present through peer interactions and role-play, but the societal dimension is not as strongly present as the other two dimensions of relevance.

Although similar learning experiences may be implemented into formal kindergarten and pre-school education, non-formal education is typically the most effective way to meet the needs of relevant science education. For instance, getting scientists to work with kids is easier through non-formal settings, as scientists have the opportunity to stay at the university without having to spend time travelling to schools. Furthermore, through non-formal education, parents are exposed to their child's education more closely. As the role of parents is important in the development of a child's interest, this extra support a child receives through parent involvement may be crucial. Undoubtedly, parents who bring their children to non-formal programs are more likely to have a personal interest in science, but even so, they may lack the tools or skills to spark their child's interest in science without programs like Little Jippos. A non-formal program therefore lowers the threshold for parents to help their children become involved with science.

As students mature (7-18 years), non-formal education may work as a powerful mean to meet the three dimensions of relevance. These dimensions should also be more balanced as the student's age (Stuckey et al., 2013). ChemistryLab Gadolin provides a great opportunity for this by giving students the possibility to do hands-on work in a university environment. Furthermore, students work on projects that are created in collaboration with companies and educators, giving the students a great opportunity to discuss societal and vocational issues. In ChemistryLab Gadolin, individual relevance is present through hands-on activities in an everyday-life contexts. Societal relevance is present through the contexts of environmental studies, chemistry in community and aspects and practices of sustainable development, for example. Vocational relevance is present through the contexts of chemical industry, visits to research laboratories and laboratory activities. ChemistryLab Gadolin has the potential to meet all three dimensions of relevance, but typically, as the visits to Gadolin are short, the teacher will have to choose which dimensions of relevance to focus on.

The strength of Gadolin is its diversity. Synergy benefits are multidimensional when universities, schools and the industry collaborate with each other. Combining all the elements together, results in more meaningful science education being available. When compared to similar science laboratories outside of Finland, Gadolin is unique as it offers age-appropriate activities to students at all school levels.

As a non-formal learning environment, Gadolin grants more time, freedom and autonomy to the learner. Positive feedback helps learners trust their own skills and supports the development of their thinking skills and improves their overall academic performance, helping them in future inquiry-based learning.

Furthermore, the way Gadolin is structured teachers have the possibility to bring their students to Gadolin to learn the same concept they would normally learn in school, but in a different environment. Teachers find this to be a very important factor.

The Millennium Youth Camp is relevant to students from an individual, societal and vocational point of view too by providing youth the possibility to network with peers and experts and work on a project related to sustainable development. Providing similar opportunities in formal education is possible, but providing them on the same scale is challenging, if not impossible. As an example, the camp gives youth the opportunity to meet not just peers from over 30 countries but also some of the world's most renowned scientists, such as winners of the Millennium Technology Prize. This type of environment is highly relevant to the individual, as they become more interested in science by working on a project that interests them. Furthermore, the vocational relevance is enhanced through working on real-life problems in collaboration with experts. Societal relevance is evident in the projects dealing with sustainable development conducted in a multicultural group with many experiences to share. Furthermore, by working on and presenting their projects, the students learn to discuss the relationships between science and society. Although these types of discussions are also possible in formal education, challenges such as fixed curriculum, lack of collaboration between subjects and teachers' lack of multidisciplinary knowledge will often result in avoiding these complex discussions.

As the lack of relevance of science education is one of the biggest problems many nations are facing today (Gilbert, 2006), the authors suggest that non-formal education should be made easily accessible for all age groups. As presented in this chapter, non-formal education offers many possibilities to meet the needs of relevant science education, possibly increasing the motivation of students, affecting their career orientation, and supporting their ability to participate in socio-scientific discussions.

As the basis for intrinsic motivation and personal interest will already be created at an early age (Eshach & Fried, 2005), exposing young students to science is important. As the children grow older, their understanding of the world will increase, giving wider opportunities for including societal relevance into education. Through the process of building a strong foundation of individual and societal relevance, students will be more exposed to the vocational relevance of science education, possibly encouraging some of the students to consider science as a career.

However, a sustainable non-formal education system cannot stand alone, but should have the support of universities and companies for it to be relevant. Furthermore, non-formal education should not be seen as a replacement for formal education, but rather as an adjacent education system that provides more freedom and possibilities for exploration, networking and in-depth learning of particular themes.

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19. USING INFORMAL LEARNING EXPERIENCES TO ENHANCE STUDENT LEARNING OUTCOMES IN CHEMISTRY

This chapter describes informal learning in secondary school chemistry. The chapter seeks to show how we might enhance student learning experiences outside school (LEOS), by considering what the literature has to say about good and bad ways of managing student learning at informal science institutions (ISIs). The first part of the chapter discusses how students learn based on modern theories of learning, with particular reference to social constructivism. Next it discusses literature about student learning experiences outside the school, and considers types of learning, particularly the relationship between formal learning, non-formal and informal learning. The chapter concludes with insights from a case study into the use of one of New Zealand's *premier science research institutions concerned with research into advanced materials and nanotechnology. It is intended that this chapter will lead to new insights into integrating informal learning carried out during LEOS and digital technologies such as Moodle to enhance student learning outcomes in chemistry.*

BACKGROUND

Science and chemistry curricula worldwide encourage schools to draw upon non-traditional resources to enhance the learning of science and chemistry; in particular to engage in learning experiences outside the classroom or the school (LEOTC, LEOS). These experiences, it is argued, serve to increase motivation to learn science and allow teachers to better link real world experiences to classroom learning.

Key themes to emerge from the literature are that LEOS, whilst possessing great potential, seldom results in enhanced learning outcomes in science and chemistry. Most 'field trips' end up being treated as a reward or fun activity, often at the end of the year after any formal assessment is completed. However, research evidence suggests that pre- and post-visit planning can enhance learning. But even then this learning remains fairly superficial and traditional in nature – focusing on what content was learned or the science center 'getting the science message across'. Hence, any learning that does occur in LEOS seems to be driven by a traditional pedagogical model and is often not related to current theories of learning.

I. Eiks & A Hofstein (Eds.), Relevant chemistry education: from theory to practice, 355–368.

Researchers have indicated that if we are to maximize learning during LEOS, we need to seek to understand the learning experience from the students' point of view; in other words, conceptualization of learning during LEOS needs to be student-centered, consistent with modern educational thinking and modern theories of learning such as constructivism.

Here we argue that we need to reconceptualize learning in LEOS to understand how it fits in with the broader educational landscape and, most importantly, with students' lives – in particular their penchant for using digital technologies. There are three broad types of learning identified in the literature: formal, non-formal and informal. Current research reported in this chapter is concerned with fostering the integration of informal/free choice learning which occurs during LEOS with classroom learning using digital technologies – in particular a learning management system (LMS) like Moodle (see below) – because this fits better with modern students' lived experiences and their 'digital world'.

MODERN THEORIES OF LEARNING

Theories of learning and the importance of context

Learning in informal contexts has been recommended as an important element in promoting interest in science, motivating student/teacher and student/student interactions and increasing knowledge (Pedretti, 2002). This is consistent with the research literature where Vygotsky (1986), who shared many of Piaget's assumptions about how children learn, suggested we need to place stronger emphasis on the social context of learning. This suggestion resulted in a 'brand' of constructivism attributed to Vygotskian thought, termed social constructivism, which emphasizes the critical importance of culture and the social context in cognitive development and learning.

The literature suggests that context is integral to what we learn, saying that knowledge is a product of the context in which it is learned (Rogoff & Lave, 1984; Solomon, 1983). Falk and Dierking (2000) defined three contexts derived from social constructivism which they argue influences learning at ISIs: (1) *personal context*-which includes the individualized prior knowledge, interest, motivation, expectation and experience the students brings to the ISI; (2) *sociocultural context*-which includes the influence of people within and outside the group on learning; and (3) *physical context*-which includes the entire physical learning environment. While learning may happen in different contexts, it is equally important to share these learning experiences, link and integrate with each other to co-construct knowledge.

Learning is seen as inextricably related to the social setting (and this need not to be a classroom), a process where students actively participate and create new meanings (Biggs, 1999; Falk & Dierking, 2000; Tal, 2012). Learning thus occurs by a process of social interchange (Gergen, 1995) whereby teachers can use LEOS to provide learning experiences for students that cannot be provided within the classroom (Kisiel, 2003). ISIs such as chemical research institutes, the focus here, can be used as experiential learning resources that complement and enrich the school curriculum. Next, we discuss the three different types of learning.

Types of learning – What teachers need to know

There are three broad types of learning identified in the literature: *formal, non-formal* and *informal.* Formal learning is typically conducted in a structured classroom, following a prescribed curriculum. An example here would be learning polymers using textbook resources and conducting relevant group activities (e.g., making models of Nylon 6,6). In contrast, non-formal learning allows for some flexibility and can take place both inside as well as outside the classroom. An example here would be a structured trip to a local plastics company where the teacher dictates all that happens and specifies what is to be learned. Informal learning is similar to non-formal learning, but the main difference is that it is characterized by the nature of some choice in learning, and is learning that is thus more learner-centered in nature. An example here would be a teacher taking students on a field trip to a plastics company but giving students the freedom to choose three different types of polymers, dissolving polymers, conducting polymers or light emitting polymers and describe how their structures and features make them suited to their intended purpose.

Bamberger and Tal (2007) coined the phrase *free choice learning* to describe informal learning for this reason. Informal learning is often characterized by students working in groups, thereby collaborating with each other using a variety of methods for interaction. Dori and Tal (2000) state that the goals of informal science education programs focus on more than content, and include fostering positive attitudes, improving confidence about doing science, as well as encouraging individuals to participate in science. LEOS and/or using different forms of communication media particularly web-based media have become a major source of social medium used for informal learning (Ryoo & Linn, 2012; Van Rens, Pilot, & Van de Schee, 2010).

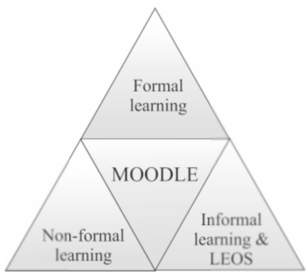

Figure 1. The three types of learning integrated by the use of the learning management system Moodle

The literature indicates that teachers who identify LEOS as destinations for education (Tunnicliffe, 1994) and take their students to an ISI for specific learning goals (Tunnicliffe, Lucas, & Osborne, 1997) need to be aware of the psychological needs of students – key factors of informal learning – and characteristics of a successful informal learning experience. Perry (1993) identified six psychological needs of ISI visitors, all of which he argues must be met for LEOS to be successful in terms of learning: (1) curiosity, (2) confidence, (3) challenge, (4) control, (5) play, and (6) communication.

The key to deriving the most from LEOS is when learning is facilitated by pre-planning and post-visit activities – all linked directly to curriculum objectives (Rennie & McClafferty, 1995; Tofield, Coll, Vyle, & Bolstad, 2003). This structure for learning gives meaning to abstract science ideas studied in the classroom (Anderson, Lucas, Ginns, & Dierking, 2000; Orion & Hofstein, 1994). This suggestion is consistent with other research which emphasizes the importance of careful planning in order to avoid learning 'disasters' and to move learning beyond the surface learning of facts or content as noted above (Hooper-Greenhill, 2000; Kisiel, 2003). Davidson, Passmore, and Anderson (2010) comment that maximum classroom input equals maximum LEOS gains. This position is supported by Falk and Dierking (2000) and Gennaro (1981) who state that emphasis must be placed on making connections between LEOS and the curriculum. They claim that this emphasis provides cognitive and affective gains.

Students are inherently excited about LEOS because it involves changes to their daily routine, but ironically their very excitement may inhibit learning. Therefore students' experiences at ISIs need to be focused by the use of well-organized teaching plans. Unfortunately, with the exception of a few studies reported in the literature, it seems that most teachers fail to provide adequate preparation for their students, and seldom plan much in the way of effective learning activities (Griffin, 1994; Griffin & Symington, 1997; Jarvis & Pell, 2005; Tofield et al., 2003).

The literature further reports that children do not necessarily link their classroom-based experiences with the curriculum that teachers taught, the pre-visit classroom activities, nor the educational objectives with their ISI visit. These experiences are seen as unrelated activities/events. There are also reports in the literature that little monitoring of learning occurs during visits – leaving students unclear about how the LEOS relates to instruction in the classroom (see, e.g., Anderson, Piscitelli, Weier, Everett, & Taylor, 2002; Kisiel, 2003). Therefore, teachers need to engage in planning for LEOS, which considers students' prior knowledge, foci, interactions, and reactions during LEOS and, most importantly, the context in order to more effectively design robust learning activities. Next, we discuss new emerging technologies and consider how they can be used in co-constructing knowledge.

New emerging technologies – Co-constructing knowledge

Young people have grown up in the digital age and most cannot imagine a world without digital media. This awareness not only helps interaction between students but also interaction between students and teachers and experts. The literature on ICT use in education suggests that its use also helps motivate students to learn

(Rodrigues, 2010). This motivational impact on students' learning helps afford ownership and control with respect to the pace of learning and choice of content (Ryoo & Linn, 2012; Van Rens et al., 2010). ICT-integrated learning in science also is reported to help enhance new literacy skills, creativity, social skills and digital competencies (Lewin, 2004; Walsh, 2007). The uses of ICT also have reportedly had an impact in the area of science interactions and collaboration between students and between students and teachers (Jonasson, 1994; Linn, 2003).

ICT has become an important interactive tool in most New Zealand classrooms. The integration of classroom learning and other activities such as LEOS can draw upon ICT – in particular learning management systems. LMSs are software applications that have a number of operational features which are useful for administrative tasks as well as having affordances for use in classroom practice. LMSs are also referred to as '*learning platforms'* and combine a range of course or subject management and pedagogical tools to provide a means of designing, building and delivering on-line learning environments. Moodle, an acronym for *Modular Object-Oriented Dynamic Learning Environment*, is an open-source software package, widely used in secondary and tertiary institutions in New Zealand, including the school used in the case study described below.

The nature of a LMS is consistent with a social constructivist theory of learning, which presupposes that learning is best achieved in social environments, and the notion that any form of communication (virtual or real) can be used to enhance the social presence of others, and thereby facilitate learning (Downes, 2005). A LMS is then a 'pedagogical space', where the teacher and the learner may be geographically separated, but are connected via knowledge construction processes, and who communicate via discussion forum, submit assignments via email or digital drop box (Downes, 2005; Siemens, 2004). This new type of social space and its social networking features can facilitate numerous types of interactions, whereby students can develop a new sense of 'self' and 'community' – something that can be mediated, negotiated and if necessary continuously renegotiated. Many research studies report that when using interactive materials, students not only learn more – and more quickly and more enjoyably – they learn the much needed life skill of learning how to learn; that is, they begin to take ownership and responsibility for their own learning (Ryoo & Linn, 2012; Siemens, 2005; Van Rens et al., 2010).

The teacher's role in informal chemistry learning

The teacher's role in facilitating LEOS is diverse, and may include planning and coordination between the ISI and the school. Jarvis and Pell (2005) noted that teacher preparation and coordination throughout the visit has a profound effect on students' engagement and science enthusiasm.

Anderson, Lucas, Ginns, and Dierking (2000) report that in order to provide better learning outcomes from out of school activities, teachers should be actively involved in planning and linking out of school visits to specific curriculum objectives, and to link these objectives directly to activities during the visit. These plans should allow for the inclusion of student field-based experience with students' own experience. There is also evidence to suggest that besides teacher preparation, other factors such as guide experience and the nature of the ISI could impact on students' learning experience (Tal & Morag, 2007; Tofield et al., 2003). Orion and Hofstein (1994), for example, stress the importance of a well-structured LEOS which they claim gives meaning to abstract science ideas studied in the classroom.

Rennie and McClafferty (1995) argue that teachers should integrate visits with their teaching programs and use out-of-school activities to complement, not replace, learning activities in classroom. In summary, it seems that the key to deriving the most from sources of out-of-school learning are that learning is facilitated by pre-planning and post-visit activities all linked directly to curriculum objectives (Tofield et al., 2003). Well-planned activities by the ISI staff also can have a positive effect on student learning, and these too need to be integrated to pre- and post-visit planning by the teacher.

While the type of learning experiences which occurs in out-of-school settings is complex and involves cognitive, affective and social aspects of learning along with multiple and interrelated outcomes, it seems clear that students learn by collaboration where knowledge construction is mediated by artefacts and dialogues (Ash & Wells, 2006). Learning is seen as a system of participatory competencies and activities, which means that individuals actively engage in group discussions to find answers to complex questions (Leinhardt & Knutson, 2004). This process is important for investigating the way school trips allow for students to discuss complex questions and the role adults play in mediating and encouraging these dialogues. Mediation, which is provided by objects, symbols and humans, is a central idea proposed by Vygotsky (1986), which is helpful to understand learning in out-of-school settings.

If Vygotsky's theory sees children develop in social or group settings, then the appropriate use of communication technology, such as computer-generated programs to mediate these dialogues, could enhance field trip experiences. Technology provides essential tools with which to accomplish the goals of a social constructivist-based classroom. There is, however, only a small body of emerging research on the contribution of digital technologies to chemistry learning in out of school settings (Rennie, 2007). Digital space allows students significant autonomy and this encourages active participation (Lewin, 2004) and students are also reported to become self-directed, negotiating their own goals, expressing meaningful ideas and displaying a strong sense of collective ownership (Willett, 2007). Peer mentoring and modelling by more knowledgeable friends, siblings and other adults are distinctive features of these informal e-learning experiences (Gerber, Cavallo, & Marek, 2001). Common interests can emerge in these digital networks and knowledge can be built collaboratively (Siemens, 2005).

Information technology can support learning that occurs outside school. Learning management systems such as Moodle provide a means for dialogue, discussion, and interactive debate that leads to the social construction of meaning. Students can 'talk' with other students, teachers, and professionals in communities far from their classroom. A LMS is used here as a learning platform which offers affordances for students to provide evidence-based arguments and explanations, to analyze and synthesize data and to defend conclusions. These activities are done by co-constructing, wikis and/or sharing documents and blogging, using new media literacies (NML). Learning can be facilitated in such a way that the perception of social presence is increased by the use of a LMS; this in turn greatly increases the ability to substitute ICT for face-to-face interactions while achieving the same learning outcomes (Richardson & Swan, 2003). Since collaborative or group learning characterizes informal learning, it is proposed here that the use of NML via LMS could be an effective way of enhancing learning outcomes in chemistry.

LEOS and informal learning in chemistry

This research project we report on here is noteworthy because it focuses on enhancing student learning, in particular via enhanced collaboration, during out-of-school experiences using digital technologies. Many science curricula worldwide including the New Zealand Curriculum (the context of this work), places a strong emphasis on contextualizing learning, and suggests that one of the ways of doing this is by taking students outside the school. As noted above, the literature indicates that LEOS helps in conceptual learning, provides enrichment, social and emotional engagement, improves attitude towards science, changes pace, and reinforces certain content or merely to have fun (Rennie & McClafferty, 1995). DeWitt and Storksdieck (2008) go on to state that increased motivation, interest and attitude might have a greater long-term cognitive impact than factual knowledge, which disappears after a short time, and this is one of the most common objectives for out-of-school visits. However, as noted above if such objectives are to be achieved, then teachers need to prepare students for these learning experiences (Gilbert & Priest, 1997).

CURRENT RESEARCH ABOUT INFORMAL LEARNING: A CASE STUDY OF LEOS AT A NANOTECHNOLOGY RESEARCH INSTITUTE

The context of this study is *Central High School* (a pseudonym), a small private school (roll ca. 200) located in a wealthy rural area in New Zealand. The research paradigm adopted in this study is the interpretive paradigm which considers both social and cultural interactions – important when studying an individual's social behaviour (Anderson & Arsenault, 1998; Guba & Lincoln, 1989). We adopted a qualitative case study approach, which is characterised by the researcher spending substantial amount of time in the educational setting; and that was the case here. Hence, multiple interviews and observations were conducted over a considerable length of time. Such intensive, ongoing use of qualitative methods is of particular importance here because we are trying to get a better understanding of the current practices involved in LEOS to help enhance the learning of chemistry by integrating all informal learning occurring during LEOS using digital technologies.

There were two phases to the work. In the first phase we sought to investigate current practice around LEOS to see if the issues (e.g., around planning or lack thereof) reported in the literature also were present in this school setting. In the second phase, we sought to draw upon the use of digital technologies including the LMS Moodle to enhance links to classroom learning.

Phase one: Traditional practice and views of LEOS

The research in this case study indicated that the LEOS was a compulsory part of the *Central High School* calendar and, for the last three years, chemistry teachers were required to take students to a chemical research institute to help enhance their knowledge of nanotechnology. Nanotechnology is a new topic in chemistry, recently included in the New Zealand Science Curriculum at Year 12 (16 years old). As a consequence, both teachers and students lack resources because there are no workbooks or study guides published which contain materials on this topic. The teachers reported using the Internet to access literature, but commented that most sites appeared to be aimed at academics or graduate research students.

All preparation for LEOS was coordinated by the senior management team – comprising of the Head of Department and Deputy Principal (neither of whom were classroom or subject teachers). The agreement between the school and the ISI was that a visit was only possible on the invitation and at the convenience of the ISI. As a consequence, there were times when students made these visits after they had completed the projects which had been assessed and graded and reported via the school portal. Twice, the visit was scheduled on the second-to-last week of the teaching year, and students looked forward to it – mainly as a reward. The teachers typically did not get enough time to discuss the findings, after the trip and one of the teachers reported that he did not see them at all because students went on camp trips in the last week of school. This teacher stated:

> At this age in time, the information is at our finger tips and there is no need to visit [this ISI]. Also, there are enough exemplars to use and we can better prepare these students for their internal assessments. Students only look forward to having a good time with their mates since they have to camp that night at a friend's place. I don't think any learning really occurs during this trip. I think it is a waste of time when we have so much to do at this time of the year. We could even get videos and show it to them to achieve the same outcome.

Observations of the field trip showed that overall, the teacher was seen to play a relatively passive role on the site visit – transporting the students to the ISI, and managing student behavior. Hence, from this phase of the study, it seems all the issues about LESO reported in the literature are present at *Central High School*.

Phase two: Integrating informal and free choice learning in chemistry via digital technologies

A *Central High School* teacher, *Mrs. Brown*, agreed to work with the researchers to enhance LEOS at the school. She first identified students of different abilities, especially those with ICT, leadership and teamwork skills before grouping her students into mixed ability groups as recommended in the literature (Jansoon, Somsook, & Coll, 2008). She also found out through informal discussions that most students had smartphones and decided that conducting polymers would be a suitable focus for their study during LEOS.

Mrs. Brown subsequently informed the ISI of the intent of the visit, and sent copies of the materials that she wished to share with the ISI staff. This ISI was located in the capital city and so the school had to book flights to travel to and from the site on the same day. She got the students to use the wiki sites on Moodle to prepare questions which they wished to explore with the ISI staff, in addition to the focus of their visit, which was to collect materials for their internal assessment. This procedure provided for some free choice learning, consistent with the recommendations from the literature.

The findings from this phase of the case study indicated that as a result of the free choice learning, most of the students wanted to know about carbon fiber – a material used to make the sailing boats used in The New Zealand America's Cup campaign – something highly topical and prevalent in the media at the time of the visit. This clearly related the topic to the students' everyday lives.

Mrs. Brown spent some time organizing the trip and planned pre- and post-visit activities. In particular she sought to link the LEOS with classroom learning and so taught her students about nanotechnology before the visit. The expected outcomes of this topic were to develop skills where students could

- Gather, processes and interpret teacher provided and/or other secondary source information about a polymer and record notes appropriately;
- Describe the development of a conducting polymer in depth;
- Give a comprehensive description of the history of the polymer's development, including reasons why a particular development path was pursued;
- Link the development of the polymer to related current or historical chemistry knowledge;
- Use chemistry vocabulary extensively to describe the development and composition of the polymer, for example, the chemical equation that describes the polymerisation process; and
- Evaluate the discovery or development with respect to its use by society, for example, the needs met by the polymer and the new challenges it presents.

During the pre-visit preparation, she helped students to develop their knowledge of polymers and electrical conductivity by teaching these topics in class. Here, she emphasized that only charged particles and delocalized electrons can conduct electricity (Figure 2).

Polyethylene Doped to remove electron

Figure 2. Schematic of a conducting polymer

Mrs. Brown explained that insulators are substances where the electrons are tightly packed and are thereby not able to move around. She discussed polyethylene as an example of an insulator, saying that it does not conduct electricity as the electrons are held in place as part of bonds between atoms. She then explained that when doped with bromine – used to remove some of the electrons, this makes ‘room’ for the remaining electrons to move, so a polymer ‘doped’ in this way can become a conductor like metals. She also pointed out a requirement for polymers to conduct is to ensure that they have alternating C=C and C−C, and that we then ‘remove some of the electrons with either bromine or iodine’.

The LMS, Moodle, is an important tool used in communication for teaching and learning. The Year 12 students used the Moodle site to collect notes from their teacher especially those who were away during those lessons. Together with notes on conducting polymers, *Mrs. Brown* also posted materials on Moodle which mainly interested students who were keen on in cars and these notes were on palladium metal used in catalytic converters. Some of the questions posted on wiki during pre-visit planning were:

Q1. What is nanotechnology? Here you should share ideas from all your readings,
Q2. How is these developments related to chemistry?
Q3. Historical developments – Here you could share the timeline, its uses during the old days and why, cost, limitations, etc.
Q4. Its use to society – Be specific and discuss the uses- both good and bad.

The different student groups used wiki sites to collaborate with each other and it was interesting to note that those who were quiet in class started to share their thoughts and ideas more easily via wikis. This is consistent with the literature, which states that digital space allows for autonomy to learn. They critiqued each other’s posting and came up with a list of questions which they wished to explore at the research institute. *Mrs. Brown’s* focus questions allowed students to discuss both, conducting polymers as well as catalytic converters all of which were relevant to student lives as well as their studies on nanotechnology.

An image of a catalytic convertor provided in one of the postings made on wiki by a student whose parents owned a car business is illustrated in Figure 3, and the text associated with the diagram follows.

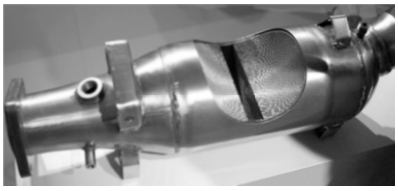

Figure 3. Diagram of a catalytic converter using palladium as a catalyst (Source: http://www.howstuffworks.com/catalytic-converter2.htm)

A catalytic converter is a product that has been used in the automotive industry to convert pollutant exhaust gases into less pollutant gases. The exhaust gases straight from a car engine consist of carbon monoxide and nitrogen oxides, which can cause hazes in larger cities, and have been proven to be harmful to respiratory health.

> A catalytic converter has millions of nano-particles of usually platinum and palladium deposited onto a honeycomb mesh, housed in a metal casing which is inserted into the exhaust stream of the vehicle. The nano-particles mean that the surface area of the catalysts is enlarged. This is because more of the atoms of the catalysts are exposed to the harmful gases that move through the chamber. Because more of the particles of gas are coming into contact with the particles of catalysts, it increases the reaction rate by decreasing the activation energy. This is because the reactions are happening on an atomic level and therefore the reaction occurs very quickly.
>
> Reduction Catalyst $2NO \rightarrow N_2 + O_2$
>
> Oxidation Catalyst $2CO + O_2 \rightarrow 2CO_2$

This outcome where students draw upon their own interests and contexts to co-construct knowledge is consistent with the literature which states that group learning, can facilitate informal learning, helps to increase motivation and helps students to link their classroom learning with real world experiences. Therefore, students take ownership of their learning and have control with respect to the pace of learning. The students in this work were able to link what they learnt in the classroom, in the digital space, and from their visit to the learning they received at the ISI. While they had all four questions to explore at the ISI, they also chose to seek knowledge in their own areas of interest, which allowed free choice learning. Examples evident here included conducting polymers, catalytic convertors and carbon fiber.

After the visit, the students used their smart phones to capture some of the 'moments' they spent at this ISI, and when returning to school, sent these digital experiences to each other. The views of the students revealed a very different perspective to the claims of the earlier quoted teacher (not *Mrs. Brown*) about the value of such LEOS before the intervention. Not only did the students enjoy learning in a different setting, they said they had the opportunity to meet the 'real scientists' and make inquiries about topics they could not do in school. They were intrigued about the scientists' appearance and demeanor, which was obviously not as expected, and thus were looking forward to visiting another science institution during the following year.

> It was fun going on the aircraft since we had never been on one before as a class. I really enjoyed the way we were received at the reception, because we were told it was a place of high security. The scientists look different; especially one of them wore a pair of shoes which is out of fashion. They are so intelligent because they answered all our questions. Chemistry is fun and I want to do chemistry again next year. Can we go to another institute like this again?

After their visit, students used the LMS Moodle to share their findings with each other and uploaded pictures and field notes which they had made at the ISI. They also shared web addresses which they received from the ISI staff, and the nanotechnology scientists. This is consistent with the literature which states that a connection between classroom and LEOS can improve both cognitive and affective gains.

It seems then, as recommended in the literature, that thorough preparation before and after the visit where students had access to both classroom and digital resources via the LMS Moodle resources helped foster a positive feeling about science which improved confidence in doing science. Linking up via Moodle and using wikis helped students to co-construct knowledge and link their knowledge to everyday life – consistent with the modern theories of learning.

CONCLUSION

There is a large body of literature which reports growing interest in schools promoting learning in out-of-school settings. These experiences provide opportunities for informal learning in chemistry; in this chapter we suggest that teachers need to integrate at school and off-site activities in their lesson planning if they are to maximize the potential learning from LEOS. Likewise, all activities both in and out of school need to draw upon pedagogies that promote active learning, self-control, real-world experiences, group work, and inquiry. The analysis of the literature and research in our work reinforces the notion that the physical environment alone cannot make a substantial impact on student learning if the appropriate pedagogy is not considered. The question that needs to be answered is whether students who are engaged in LEOS improve their understanding of chemistry. Our conclusion is that we have identified a way forward by employing the use of digital technologies – something very natural to modern students who are 'digital-natives' – to integrate informal learning which occurs during LEOS with the curriculum taught in school.

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20. PROFESSIONAL DEVELOPMENT OF CHEMISTRY TEACHERS FOR RELEVANT CHEMISTRY EDUCATION

There is no doubt (and this is highly based on research studies) that the teacher is the key factor in the process of implementing science curricula in general, and in teaching chemistry in particular. The teachers' content knowledge and pedagogical content knowledge, which are essential components of teachers' professional knowledge base, ensure effective teaching and learning. This chapter discusses how chemistry studies can be made relevant by prospective teachers and those who are already teaching. Thus, the teachers, both those who are in the pre-service and those who are in the in-service phase of their professional development should have among their tools instructional approaches to make the learning of chemistry relevant: personally, socially, and vocationally. In this chapter we discuss the theoretical background of this issue and present ideas and methods to be implemented by professional development providers for developing a sense of importance regarding making chemistry education more relevant.

INTRODUCTION

Throughout the last 60 years the goals and objectives for science teaching and learning have undergone changes many times, often leading to reforms in the way the science curriculum was developed, taught, and learned. Five key factors influence a change in curriculum goals: The learners (target population), the teachers, the science content, the context of learning and teaching both in and out of school, as well as the assessment of students' achievement and progress. One of the key factors regarding curriculum change is the teachers themselves. In general, teachers are reluctant to accept radical changes and often do not implement them in accordance with the rationale for the change suggested by the curriculum developers. Such changes may not be aligned with teachers' existing views and practices, and may require new knowledge, perhaps content knowledge (CK), or its related pedagogical content knowledge (PCK). Important factors influencing teachers' responses to changes include personal characteristics, cultural norms (e.g., the role of questioning), the professional status of the teacher, the teacher's understanding of the proposed change and its rationale, and systemic approaches towards realizing students' future career opportunities.

I. Eilks & A. Hofstein (Eds.), Relevant Chemistry Education – From Theory to Practice, 369–386.

A growing body of evidence suggests that implementing a curriculum by central professional bodies in what is called "top-down" fashion, whereby teachers are expected to only implement the developers' philosophy, ideas, and intentions, has often proved to be ineffective in introducing educational and curricular innovations into schools. One conclusion that comes from decades of studying the success and failure of a wide variety of curriculum innovations is that innovations are generally ineffective when they are simply imposed on the teachers and that innovations succeed when teachers feel a sense of ownership of the innovation (Ogborn, 2002).

This chapter is divided into two parts, namely: (1) strategies that can be used in the context of the pre-service phase of teachers' professional development in order to promote awareness and skills for enhancing the relevance when teaching chemistry, and (2) an example of an in-service continuous professional development program to initiate changes in the curriculum and pedagogy of chemistry teaching. Note that in principle, the examples and pedagogies that are used both in the pre- and the in-service phases of the chemistry teachers' professional career can be very similar. In both cases the key idea is to intensively involve the teachers (or the future teachers) in the development and thereafter in the implementation of relevant chemistry topics and their related issues in the classroom. There are, however, differences in teachers' self-efficacy related to implementing relevant ideas. In general, novice teachers in many countries can be considered as less flexible in adopting new pedagogical ideas compared with more experienced ones.

In general, teachers tend to accept a new curriculum, new pedagogical interventions, new topics to be taught, and new assessment methods more easily when they are in alignment with the learning goals they personally value or when they perceive that the innovation provides an effective solution to problems they encounter in their respective classroom or school. There are several factors that seem to be crucial for teachers when they adopt curricular changes, such as assumptions about the potential success of a new course, the teachers' perceptions of its effects on students' learning and attitudes, teachers' views about students' interest and motivation, perceived learning outcomes, and enhancement of self-regulated learning. The importance of supplementing the curriculum with materials developed by school teachers either in schools or districts in the context of long-term professional development initiatives has also long been recognized (Mamlok-Naaman, Hofstein, & Penick, 2007). In addition, it was stated that teachers who can experience the new approaches themselves and/or that are intensively involved in the process of curriculum development will eventually develop a high sense of ownership related to the materials and pedagogies in which they were involved. This should include developing instructional techniques aligned with the nature of the content and assessment methods that are aligned with the instructional techniques as well as actively implementing these materials in the chemistry classroom. Ogborn (2002), in the UK, wrote that:

> One of the strongest conclusions to come out of decades of studies of the success and failure of a wide variety of curriculum innovations is that innovations succeeded when teachers feel a sense of *ownership* of the

> innovation: that it belongs to them and is not simply imposed on them. (p. 144)

A theoretical summary regarding the issue of ownership in the context of education was presented by a group of educators in the Netherlands (Ketelaar, Beijaard, Henny, & Den Brok, 2012), who claimed that the issue of ownership, as related to education, has not been researched sufficiently. They wrote, based on Van Veen and Sleegers (2006), that:

> Teachers who are frequently involved in educational innovations their reaction to the implementation of an innovation is largely dependent on whether they perceive identities as being reinforced or threatened by the proposed changes. (p. 273)

In addition, a sense of ownership might be enhanced if the educational innovation is aligned with the teachers' personal beliefs (Beijaard, Maijer, & Verloop, 2004) and if the teachers support the idea and goals of the innovation and are willing to invest sufficient time to be part of the innovation. Clearly, developing a sense of ownership is a very slow and intensive process. It is suggested that it should start in the pre-service phase of teacher training and should be continued through Continuous Professional Development (CPD) procedures. In a good CPD, teachers are provided with opportunities to develop personally, professionally, and socially, as suggested by Bell and Gilbert (1996) in their book: *Teacher development: A model from science education*.

Personal development in the context of science teachers refers to effective development that involves attending to feelings about the change process, about being a teacher, being a leader, and about science education. Professional development in the pre- and in-service phases involves, among other components, the use of different teaching skills in order to change those concepts and beliefs connected with the skills associated with teaching science (in our case chemistry). Thus, teaching chemistry in the context of teachers' professional development includes both content knowledge as well as pedagogical content knowledge. The third component of Bell and Gilberts' (1994; 1996) teachers' enhancement model is the social dimension. This dimension involves learning to work with other people in the educational system in new ways.

Clearly, the professional development of teachers in these three dimensions is a long-term process in which the teachers are at the center of the professional enhancement process including decision making and active development of learning materials and instructional techniques, both the content as well as the related pedagogies. This rather ambitious goal might be attained through a chain of activities starting from pre-service training and continuing as a life-long learning process. Some ideas regarding how this process can be supported will be outlined in the following sections.

PROMOTING RELEVANT CHEMISTRY EDUCATION IN TEACHERS' PRE-SERVICE TRAINING

Promoting skills that will make the relevance of chemistry visible in teaching

According to the theory of situated cognition (Greeno, 1998), sustainable learning and becoming able to apply the chemistry theory learned only takes place if the learning process is embedded into and starting from a certain context that makes sense to the learner (Figure 1). Science learning should start from contexts that are connected to the students' lives, their prior experiences, their interests, and therefore, the contexts should make sense to them. However, contexts should also be chosen in such a way that they are related to the later expected application of the learned knowledge. For the majority of the students who will not embark on a career as a chemist (or chemistry related professions), such a context will not come from academic chemistry. In contrast, students' everyday lives and the society in which they live have potential to offer meaningful contexts to the students. Often teachers' training and thereafter the teaching of chemistry in schools tend to put the subject first and the application second.

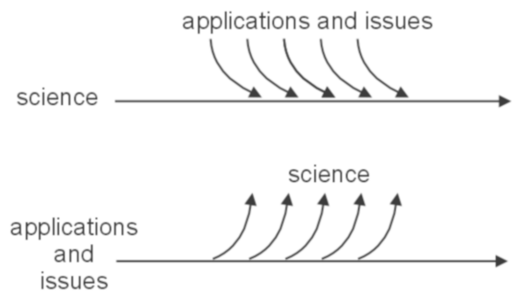

Figure 1. Traditional curricula driven by the structure of the discipline vs. curricula driven by applications and issues (Holman, 1987)

Since the 1980s, projects have been launched in many countries with the goal of teaching chemistry in a context-based approach. Some common characteristics of these approaches were described by Bennett and Lubben (2006):

- Using everyday contexts and applications of science as the starting point for developing scientific (in our case chemistry) understanding,
- Adopting student-centered 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 an increasingly elaborate understanding), and
- Using a "need-to-know" approach.

Here we shall present several examples of developing knowledge of chemistry, taking into account its meaning to students' everyday-life and environment. The modules were developed as part of a course on "Methods for Teaching Chemistry".

In developing these modules, stress was placed on the subject's relevance to everyday life and on learning by the inquiry method, which can arouse curiosity, enthusiasm, and motivation to learn.

It is suggested that science education in school should be taught using the inquiry method (NRC, 1996), based on a dynamic, active, mediating, and meaningful approach. Students should work together and must act simultaneously at two levels so that their creative powers will be aroused (Zidani, Kortam, & Hugerat, 2003; Marshall, 2010). However, such an approach has similar potential also for teaching chemistry student teachers, both in learning chemistry and learning how to teach chemistry. In an example from a course on acid and base chemistry, the instructor announced that today's lesson will be about "bee stings", as one example for distinguishing between acids and bases. The students were then asked: "*What is the connection between bee stings and acids and bases.*" This question initiated a context-based learning process. One of the student's reactions was: "*Only now do I understand how I will become a different teacher in the future, when I'll teach chemistry*!"

In order to provide the student teachers with an opportunity to understand the meaning of context-based approaches, each student was asked to present a context-based topic twice to different audiences. Before the lab class, the audience consisted of student teachers of chemistry and other natural sciences. Therefore, there were many constructive comments and expected questions that students asked in the context of peer-learning. After the lab the student teachers presented their topic in front of a general audience. This audience did not consist of prospective chemistry teachers or other science teachers. This provided the student teachers with a challenge of how the topic could be best presented. Therefore, changes had to be made in the experiment so that the result would be unexpected and its relevance to everyday life would be clear enough to arouse the interest of a general audience. It is suggested that this activity can guide future teachers regarding how to prepare challenging chemistry lessons. In this way, it attempts to accommodate all students' perceptions of relevance – also those who are not intrinsically motivated to learn chemistry. However, in both cases it is important to ask why a topic is relevant and to whom.

After the experiments were over, two students, who were not studying science, talked to the lecturer after they had watched the presentation. One of them claimed to have prepared ice cream and plastic better than those he saw in the presentation and the other complained that an experiment with red cabbage resulted in very weak colors and that the experiment had failed. He asked for a written recipe. The reactions of the members of the audience who were not chemistry teachers or natural science teachers indicated that practical demonstrations and connections to everyday life could make chemistry relevant in the eyes of non-experts. The same might be true if the student teachers would apply this way of thinking when working as teachers in the future.

Another interesting example was provided by a trainee who planned to become a language teacher in the future. He asked to use the school laboratory together with the lab technician and the chemistry teacher in order to prepare an experiment taken from everyday life that was considered be relevant to his students. He wanted to ask them to prepare a report on what they saw in terms of fluent language. If this is what happened after just one presentation, then we can conclude that courses for student teachers about how to relate chemistry to everyday life – or even more, to change existing courses to include this perspective – might have significant effects on the way chemistry is later taught in schools.

Such an integrated change within chemistry courses can be implemented by coupling content-related and pedagogy-centered courses. Such a combination can be implemented, for example, in “The General Chemistry Lab” and “Methods for Teaching Chemistry” courses. Such a combination can familiarize students with how to implement active, dynamic, and meaningful inter-disciplinary learning. In one of our examples, student teachers in the freshman course “The General Chemistry Lab” were provided with basic tools for performing relevant experiments as a means of improving scientific thinking and in order to enable students to perceive and internalize a variety of ways to conduct experiments. In the parallel “Methods for Teaching Chemistry” course the students received a syllabus and were asked to construct lesson plans that include creative instructions. Students were required to plan experiments using mainly domestic materials to make the practical activity authentic (Hugerat & Basheer, 2001; Basheer & Hugerat, 2006). First, the students explained the experiment to be performed and its connection to everyday life, usually the home and the kitchen. The students planned a number of simple experiments that were not carried out as part of the course itself but were presented in the college courtyard. The other students observed the experiment. We noticed that students from many different domains seemed to be interested. They asked many questions and received explanations at various levels. At the end of each experiment the chemistry students reported a high degree of satisfaction. They also made some creative suggestions (Hugerat, Basheer, & Kortam, 2013).

The following conclusions were drawn after a change in the pedagogy, along with the examples described here: When student teachers are put in the role of teachers, a creative thought process takes place that produces advanced analytic skills on the subject. Student teachers become encouraged and more highly motivated. Greater awareness of the importance of inquiry processes is raised, which constitutes a necessary condition for advanced learning in science. More powerful student-teacher interactions and examples of the teachers’ mediating process were observed. A “cocktail” of teaching strategies was used for all topics. The importance of interdisciplinarity in teaching was also noted.

Towards developing course modules for relevant chemistry education

Systemic and evidence-based curriculum development for chemistry teachers is needed for achieving more relevant and effective teaching and learning as well as for innovating the curriculum. Thus, it is important to implement new topics and pedagogies that continuously emerge in science education and that correspond to teacher education programs. One such new topic is sustainable chemistry, and one new pedagogical approach related to it is Education for Sustainable Development (ESD) (see Chapter 9 by Sjöström et al. in this book).

In a recent review of the role of ESD in secondary chemistry education, Burmeister, Rauch, and Eilks (2012) strongly justified covering ESD issues in the chemistry classroom, in chemistry teacher training, and in chemistry education research in order to achieve more relevant chemistry education (see also Chapter 9 by Sjöström et al. in this book). The special emphasis that chemistry education should have can be derived from the highly unique economic role of industrial chemistry in every developed society. ESD in connection to chemistry education was suggested to have potential to contribute to all three domains of relevant chemistry teaching, since it is relevant for individual action, e.g., in cases involving consumption of resources, participation in societal debates about issues of sustainable development, or careers related to sustainable chemistry and technology (Eilks & Hofstein, 2014). This point of view justifies thoroughly implementing learning about sustainability issues and ESD into chemistry teacher education to promote the relevance of chemistry education in schools.

According to the claim of developing chemistry teacher education based on research, Burmeister and Eilks (2013b) recently reported the development of a chemistry teacher education module in German chemistry teacher education. As a basis for developing the module, two empirical studies about the knowledge base of chemistry student teachers and practicing chemistry teachers were conducted. Both studies showed that there were very positive attitudes towards teaching and learning about sustainability issues and green chemistry in chemistry education; however, both the student teachers and the experienced teachers possessed hardly any actual concepts and knowledge of models about sustainability and green chemistry. They also lacked theory-based knowledge about how to operate ESD in general and in chemistry classes in particular (Burmeister & Eilks, 2013a; Burmeister, Schmidt-Jacob, & Eilks, 2013).

To overcome this lack development of a specific course module was initiated using the model of Participatory Action Research in science education (Eilks & Ralle, 2002). For almost a decade this model has been used for chemistry education curriculum development and classroom research. The project reported by Burmeister and Eilks (2013b) represents one of the first approaches for transferring the PAR model outlined for school education reform in order to innovate higher education. Also, in teacher education development projects, PAR seeks to cyclically optimize teaching practices that are supported by research evidence. Here, also, PAR is conducted in a cooperative process by researchers and practitioners involved in the developmental research process, although Burmeister and Eilks (2013b) also described a slight change in the roles and perspectives of the persons acting here. Nevertheless, this approach offers a chance to combine internal and external viewpoints regarding practice, which is where innovation is actually thought to take place.

In this specific case, four developmental cycles in four consecutive academic years were conducted from 2009 to 2012. Each cycle was evaluated using student feedback, classroom observations, group discussions, and student feedback questionnaires. Fifty-eight students participated in the cycles of development. So far, more than 100 student teachers have participated in the course since 2009. All data from the evaluation were qualitatively analyzed. The analysis was used for cyclical optimization of the course, including insights into its feasibility and effects.

The structure of the course developed in this project encompasses different topics. The course module takes six weeks with one 90-minute session per week. Table 1 presents an overview of the different sessions. The pedagogical ideas implemented in the learning process within the course module are given in more detail in Burmeister and Eilks (2013b).

Table 1. Overview of the course module structure an ESD in chemistry education

Session 1	Assessing the a priori knowledge and attitudes towards sustainability and ESD using a research questionnaire based on Burmeister and Eilks (2013a) Lecture on the historical genesis and modern concepts of sustainability Overview of the course and introduction to a WebQuest on sustainability and green chemistry (Burmeister, Jokmin & Eilks, 2012)
Session 2	Conducting the WebQuest on issues of sustainability and the concept of green chemistry leading to the role played by presenting different views towards green chemistry
Session 3	Jigsaw classroom activities on educational policy papers about ESD in German school education
Session 4	Analyzing a lesson plan on teaching about plastics with an ESD emphasis, which mimics the product testing method in order to evaluate plastics in the foreground of sustainability criteria, as described in Burmeister, von Döhlen and Eilks (2013)
Session 5	Educational board game based on green chemistry in the chemical industry developed by Coffey (2013)
Session 6	Lecture summing up the course content and discussing basic models how to connect ESD and chemistry education Assessing learning success with reference to the initial questionnaire and data about student teachers' knowledge of sustainability and ESD from the accompanying research

Overall, the participants responded very positively to the course. The student teachers stated that the course module was interesting, important, and valuable for later acting as chemistry teachers in school. The student teachers also emphasized that they had learned a lot and that they now felt more competent in the area of sustainability and ESD. Criticism was rare and occurred only briefly in the questionnaires and the group discussions. The criticism even diminished because of improvements in the course structure and materials from the first to fourth application in the consecutive PAR cycles. In the end, it is hoped that the participants maintained their positive attitudes but also added corresponding knowledge and skills to utilize ESD in chemistry education and to utilize the great potential of ESD in making chemistry learning more relevant. Today, many elements of the course design are also used for in-service chemistry teacher professional development workshops.

Course session for reflecting on the relevance of chemistry education

This section describes a session implemented in a second-year pre-service chemistry teacher education course. It is part of a module on the basic theories of science learning, the general orientation of a chemistry curriculum, the objectives of chemistry teaching, assessment, and large-scale international comparative studies.

The session is initiated by the question: Why do you think it is relevant to ask high-school students to engage in compulsory chemistry lessons? Ideas are written by the student teachers on cards and are clustered on the blackboard. Typical answers concern issues like coping with chemistry-related questions in everyday life, understanding the nature of chemistry, and helping to develop problem-solving skills. They also cover skill development for societal participation, raising environmental awareness, or learning about businesses and jobs in the chemical industry.

Starting with the students' clusters, a definition of relevance is introduced, as suggested by Stuckey, Hofstein, Mamlok-Naaman, and Eilks (2013), and as it constitutes the theoretical framework of this book (see the prologue in Chapter 1 in this book). The different dimensions of relevance are presented, namely, individual, societal, and vocational relevance. It is also mentioned that each of the layers in the relevance model by Stuckey et al. (2013) covers both an intrinsic to extrinsic as well as a present to future range. The clusters suggested by the student teachers are reflected in the foreground of this model.

In a second working phase during the seminar the students are introduced to the layer model by Stuckey et al. (2013), however, without the illustrative entries from the corresponding publication (Figure 2). The students' task is to determine potential entries for the twelve corners of the three layers from their cards and other sources. Since the model is new to the students and most of the potential reasons for incorporating chemistry into the curriculum cannot easily be sorted in the model, this activity generally leads to intense discussions.

In a final working phase, the students are asked to reflect on which role the individual learners play when objectives are to be defined when considering the concept of relevant chemistry education. Here especially the age of the students, but also their interests, socio-educational or cultural backgrounds generally come up in the discussions. Considering the age, it always becomes clear that the individual dimension might be the most important factor for quite young students where the societal and vocational dimensions grow in importance with the years (Figure 3). However, other influencing factors might also be discussed.

Finally, this session leads to additional sessions on basic frameworks for defining the objectives for relevant chemistry education, e.g., the concepts of

Activity Theory, Scientific Literacy for all, or *Allgemeinbildung*, as discussed by Belova et al. (2013). The question of relevant science education also introduces a discussion about the relationship of the individual with science and society, inspired by the model of the science-to-society relationship, as suggested by Belova et al. in this book (Chapter 10).

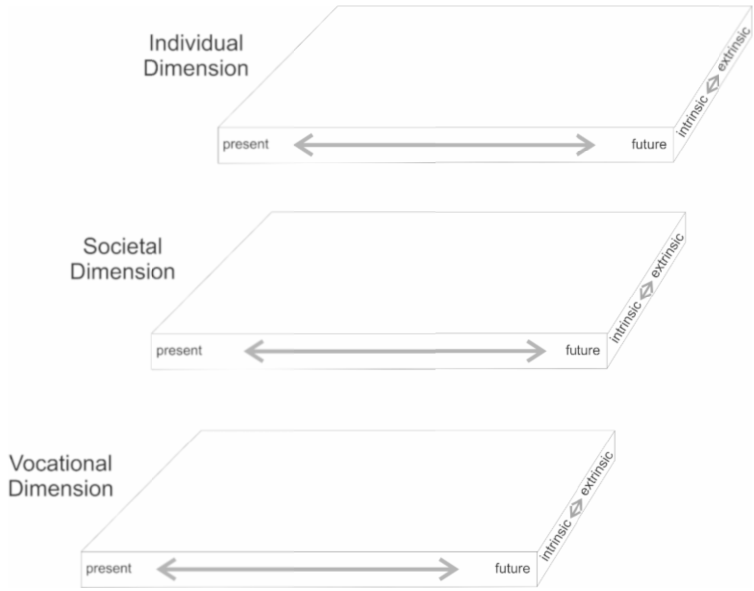

Figure 2. The relevance model by Stuckey et al. (2013) without the illustrative examples (Compare it to the model given in the prologue chapter in this book)

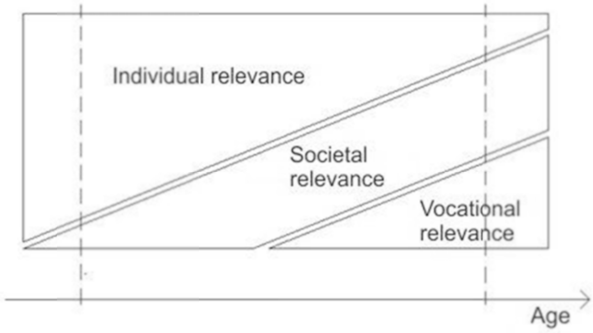

Figure 3. The shift of emphasis in the different dimensions of relevance as discussed in Stuckey et al. (2013)

CONTINUOUS PROFESSIONAL DEVELOPMENT FOR RELEVANT CHEMISTRY EDUCATION

The teacher as a curriculum developer

The importance of supplementing curriculum guides and students' learning units (for example) with materials developed by school teachers, either through the support they obtain in CPD in-service workshops or by working in schools with small collaborative groups of teachers, has been noted by Bennett and Lubben (2006) in a paper related to teaching chemistry in the context of CPD in the UK (Salters) and in Germany (*Chemie im Kontext*: Parchmann et al., 2006). It was suggested that several factors seem to be relevant to teachers when adopting a change in the curriculum, such as judging the success of a newly developed course, the teachers' perceptions in relation to the potential effect on the students' learning and attitudes, interest, and motivation, the perceived learning outcomes and enhancement of self-regulated learning. In the process of developing the curriculum teachers learn new science content, collaborate with peers, and experts develop new assessment frameworks and tools that are aligned with the new content and instructional methods developed as well as examine the current classroom practice. Loucks-Horsley, Hewoson, Love, and Stiles (1998) elaborated on the idea of using the teacher as a curriculum developer as a strategy for in-service professional development of teachers. They wrote that that:

> Throughout the CPD, based on the teachers' intensive [efforts] in curriculum development and implementation processes, teachers can increase their understanding of both content and pedagogical content knowledge by thinking carefully about broad goals of the curriculum and the specific concepts, skills, and attitudes that students need to acquire. (p. 81)

In addition to the teacher-based curriculum development, one can consider another approach to the bottom-up curriculum approach, namely, school-based curriculum development (SBCD). This can be viewed as an endeavour aimed at diminishing dependency on the central national science curricula, increasing the school's autonomy, and enhancing the teachers' sense of ownership. A central aspect of SBCD relates to teachers' professional development and entails the transfer of responsibility or ownership to the teacher. The basic assumption is that SBCD and teachers' professional development are two coupled processes. Another aspect that should be considered is the time required for implementing a new curriculum that has been changed. Without providing adequate time for professional growth, it is unlikely that teachers will effectively develop and implement new teaching practices.

Development of teachers' sense of ownership within teachers' continuous professional development

In their book on professional development in the sciences, Loucks-Horsley et al. (1998) presented several models that can be used for science and mathematics teachers' professional growth. It is beyond the scope of this chapter to discuss and analyse all the models they presented; however, two of them are very much aligned with the topic of this chapter, namely the focus group and the teacher as curriculum developer models. In the context of these key models, Sparks and Loucks-Horsley (1989) offer the following five models of professional development:

Individually Guided Development: The teacher designs his or her learning activities. An assumption of this model is that individuals are motivated by being able to select their own learning goals and means for accomplishing those goals. A belief that underlies this model is that self-directed development empowers teachers to address their own problems and, by so doing, creates a sense of professionalism.

Observation and Assessment: Instructional practices are improved if a colleague or other person observes a teacher's classroom and provides feedback. Having someone else in the classroom to view instruction and provide feedback or reflection also is a powerful way to impact classroom behaviour. The person observing acts as another set of 'eyes and ears' for the teacher. Observers also learn as they view their colleagues in action.

Involvement in a Development or Improvement Process: Systemic school-improvement processes typically involve assessing current practices and determining a problem whose solution will improve student outcomes. The solution might include developing curricula, designing programs, or changing classroom practice. New skills or knowledge may be required and can be attained through reading, discussion, observation, training, and experimentation. Consequently, involvement in the improvement process can result in many new skills, attitudes, and behaviours.

Inquiry: Teachers formulate questions about their own practice and pursue answers to those questions. Inquiry involves the identification of a problem, data collection (from the research literature and classroom data), data analysis, and changes in practice followed by the collection of additional data. The inquiry can be done individually or in small groups. This model is built on the belief that the mark of a professional teacher is the ability to take "reflective action."

Training. A training design includes an expert presenter who selects the objectives, learning activities, and outcomes. Usually the outcomes involve awareness, knowledge, or skill development, but changes in attitude transfer of training, and 'executive control' needs to be addressed as well. The improvement of teachers' thinking should be a critical outcome of any training program. The most effective training programs include exploration of theory, demonstrations of practice, supervised trials of new skills with feedback on performance, and coaching within the workplace.

As mentioned before, the shared features between these approaches are that all are highly based on the intensive and comprehensive involvement of the teachers in all the curricular facets including implementing the new learning materials in the teachers' science classes.

An example: Implementing an effective CPD model

An example to illustrate teachers' involvement in the creation and implementation of learning materials is PROFILES (Professional Reflection Oriented Focus on Inquiry-based Learning and Education through Science) (Bolte, Holbrook, & Rauch, 2012), which is a CPD initiative that was conducted – among the many other partners – at the Weizmann Institute of Science, Israel, over a period of two academic years 2011-2014. During two CPD cycles, 50 Israeli chemistry teachers were involved in developing relevant-oriented chemistry modules. The development of the modules constitutes several stages that were based on collaborative efforts with peers and the CPD providers:

- Choosing the theme of the module in alignment with the abilities and interests of their classroom student population,
- Collecting correct and valid scientific backgrounds, and
- Designing pedagogical interventions aligned with content and context.

All these stages fully represented the PROFILES key issues and pedagogies, namely, relevance, inquiry interventions, and decision making. Nevertheless, there were important benchmarks in developing the modules: The design of the first scenario, the design of the inquiry-based activity, which should lead to the decision-making process and to maintaining the timing that was given by the CPD providers.

All the modules that were developed were original (for more details relating to the modules that were translated to English, see: http://stwww.weizmann.ac.il/g-chem/profiles/chomarim5.html). Among the modules that were developed are the following, which are all chemistry-based:

- "Biodiesel": The use of an alternative source of energy
- "Sun screen ointment": Which kind to use?
- "To drink or not to drink": The quality of drinking water
- "Energy drinks": Are they healthy to consume?
- "Plastic": Should we reduce its use?

Note that each of the topics includes a question that initiates students' decision-making processes.

The pedagogy of teaching PROFILES modules

The educational approach underlying the learning materials (modules) presented here is "educating through science", meaning that while engaging in and discussing socio-scientific issues, students develop an awareness of their environment and acquire skills for life: asking questions, presenting arguments, making decisions, and developing inquiry skills. Dealing with these issues requires acquiring scientific knowledge, which is obtained for a purpose, e.g., having to take a stand or make a decision. Therefore, we achieve a number of targets simultaneously:

learning science content, acquiring skills, as well as awareness of and taking a stand in a socio-scientific context.

The learning materials (modules) are in line with the objectives described and were developed by teachers who identified themselves with these goals in mind during the CPD in which they were involved. The modules have a consistent structure: (1) students' activities, (2) a teachers' guide that includes assessing the students' activities, instructions for their implementation in class, and (3) a theoretical background on the scientific content. The students' activities also have a common structure, which leads the student from a socio-scientific issue to a decision-making task. It begins with a scenario that exposes and engages the student in a socio-scientific issue; it evolves with content knowledge acquisition and inquiry that the student needs to make a proper and reasonable decision regarding the issue presented in the scenario.

Teachers who developed their own modules also developed a sense of ownership regarding the pedagogical approach and towards the related learning materials developed and consequently, their classroom teaching was more qualitative and meaningful. Some of these teachers felt the need to share their experience with other teachers; the dissemination was carried out at several levels: sharing it with their staff in school, presenting learning materials at chemistry teachers' conferences, and writing articles in various teachers' journals. An example of a module developed by chemistry teachers in the context of a CPD program is presented in Figure 4.

PLASTIC: REDUCE THE USE!

The module "Plastic: Reduce the use!" is designed to expose the students to the convenient use of plastic products, on the one hand, and to the environmental impact caused by over-using those products, on the other hand. We, the developers of this module, hope that this module will develop in chemistry students a sense of responsibility regarding the environment, by increasing their awareness of the environmental impact of non-biodegradable polymers and by exposing them to ways of reducing damages such as recycling and use of alternative biodegradable materials. In this way, our students might become our "ambassadors" for communicating the importance of this issue at home.

At the beginning of the module, the students are shown pictures of environmental pollution caused by plastic products and dead animals lying on a shore that is full of plastic bags. The goal of this activity is to affect students emotionally.

The students are requested to answer some questions about their feelings and thoughts regarding the pictures:

- How do you feel when you look at the picture?
- Does it bother you to see the picture? If so, why? If not, why?
- What would you like to do after seeing the picture? Write down at least two ideas.

After raising the issue, students become acquainted with the basic and relevant scientific concepts related to polymers such as the nature of polymers, the repeating unit, recycling, and biodegradable polymers. The students need to know these concepts in order to make better decisions at the end of the module.

The following activity again addresses the students' emotional aspects of the issues: a story about a sea turtle that ate a plastic bag and needed to undergo surgery to survive. At this point, students may have acquired enough knowledge and understanding to answer some questions that they asked previously at the end of the story, for example:

- Who is responsible for the damage to the sea turtle?
- Why is food not a problem when taken into the stomach, but plastic bags are?
- Why are plastics so resistant to decomposition?
- How can plastics bags be made harmless after use?

Based on their everyday life, the students are not familiar with soluble polymers. In order to understand why the turtle had to undergo surgery, students conducted an experiment to test the solubility in water of two polymers: Polyethylene and Polyvinyl alcohol, because one of the important stages in the degradation process is solubility.

The decision-making activity, which sums up the module, was a result of the students' emotional involvement and the cognitive change that they underwent. The students used a tool called "analysis of profit gain and loss" in their decision-making process. They received a two-dimensional table; the first dimension showed several alternatives for reducing the use of non-biodegradable plastic waste, such as consuming less, use of biodegradable bags, participating in campaigns to collect bottles for recycling, limiting the production of non-biodegradable plastics, taxing the production of polyethylene bags, and subsidizing biodegradable plastics. The second dimension of the table shows criteria that may be affected by the first dimension for better or worse, such as available space at waste sites, terrain conditions, employment of workers in factories that produce polymers, the environment, and the price of useful products. The students were asked to think about how each alternative can affect any given criterion. In addition, they were asked to offer more alternatives and other criteria. At the end of this activity, each group decided which one or more alternatives they would choose in order to decrease the environmental damage caused by non-degradable plastic materials. At the end of the process, each group presented to the class its decision and why they chose it.

Figure 4. The development of the module on "Plastic: Should we reduce its use?"

Implementation of the modules in the chemistry classrooms

Following the developmental phase, the teachers tried out the modules in their respective classrooms. Clearly, this is the phase in which the teachers implemented their CPD ideas and acted as reflective practitioners. This phase is, in the teachers' eyes, the most important phase since, through implementation, they discovered how the PROFILES philosophy and approach are actually implemented by using the module.

CONCLUSION

For several years, the approach of 'socio-scientific issue-based' science teaching has offered an opportunity to extend the social dimension and its applications for science classroom teaching (Bodzin & Mamlok, 2000; Sadler, 2004). It is suggested that authentic and controversial socio-scientific issues and debates involving current social affairs, provide opportunities to make science teaching and learning more relevant. This is in fact a call for development of new curricular models should be implemented to promote interest and motivation among students (Marks & Eilks, 2009). In teachers' discussions about relevance in science education, the student teachers and especially the experienced teachers suggested that such a model of the meaning of relevance in science education can serve as a beneficial tool for reflecting on their curriculum, textbooks, or teaching practices. It became clear that such a model could help one reflect on the current status of and highlight the frequently more neglected societal and vocational dimensions of science education. It may be helpful to adopt the model of relevance in pre- and in-service chemistry teacher training and support the teachers in finding an approach for implementing all three perspectives into their chemistry curriculum in a more balanced way.

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