Relevant Chemistry Education
From Theory to Practice
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This book is aimed at chemistry teachers, teacher educators, chemistry education researchers, and all those who are interested in increasing the relevance of chemistry teaching and learning as well as students’ perception of it. The book consists of 20 chapters. Each chapter focuses on a certain issue related to the relevance of chemistry education. These chapters are based on a recently suggested model of the relevance of science education, encompassing individual, societal, and vocational relevance, its present and future implications, as well as its intrinsic and extrinsic aspects.

“Two highly distinguished chemical educators, Ingo Eilks and Avi Hofstein, have brought together 40 internationally renowned colleagues from 16 countries to offer an authoritative view of chemistry teaching today. Between them, the authors, in 20 chapters, give an exceptional description of the current state of chemical education and signpost the future in both research and in the classroom. There is special emphasis on the many attempts to enthuse students with an understanding of the central science, chemistry, which will be helped by having an appreciation of the role of the science in today’s world. Themes which transcend all education such as collaborative work, communication skills, attitudes, inquiry learning and teaching, and problem solving are covered in detail and used in the context of teaching modern chemistry. The book is divided into four parts which describe the individual, the societal, the vocational and economic, and the non-formal dimensions and the editors bring all the disparate leads into a coherent narrative, that will be highly satisfying to experienced and new researchers and to teachers with the daunting task of teaching such an intellectually demanding subject. Just a brief glance at the index and the references will convince anyone interested in chemical education that this book is well worth studying: It is scholarly and readable and has tackled the most important issues in chemical education today and in the foreseeable future.” – Professor David Waddington, Emeritus Professor in Chemistry Education, University of York, United Kingdom
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CONTENTS

Chapter 1: From some historical reflections on the issue of relevance of chemistry education towards a model and an advance organizer – A prologue
Ingo Eilks & Avi Hofstein ...................................................................................................................... 1

SECTION 1: HIGHLIGHTING THE INDIVIDUAL DIMENSION OF RELEVANT CHEMISTRY EDUCATION

Chapter 2: Why is it relevant to learn the big ideas in chemistry at school?
Onno de Jong & Vicente Talanquer ........................................................................................................ 11

Chapter 3: Chemistry and everyday life: Relating secondary school chemistry to the current and future lives of students
Peter E. Childs, Sarah M. Hayes & Anne O’Dwyer .............................................................................. 33

Chapter 4: Learning chemistry to enrich students’ views on the world they live in
Hannah Sevian & Astrid M. W. Buïte ...................................................................................................... 55

Chapter 5: Epistemic relevance and learning chemistry in an academic context
Keith S. Taber ............................................................................................................................................ 79

Chapter 6: The role of values in chemistry education
Deborah Corrigan, Rebecca Cooper & Stephen Keast .............................................................................. 101

Chapter 7: Promoting metacognitive skills in the context of chemistry education
Yehudit Judy Dori & Shirly Avargil .......................................................................................................... 119

Chapter 8: Promoting argumentation in the context of chemistry stories
Sibel Erduran & Aybuke Pabuccu ............................................................................................................. 143

SECTION 2: HIGHLIGHTING THE SOCIETAL DIMENSION OF RELEVANT CHEMISTRY EDUCATION

Chapter 9: Chemistry education for sustainability
Jesper Sjöström, Franz Rauch & Ingo Eilks ............................................................................................ 163

Chapter 10: The idea of filtered information and the learning about the use of chemistry-related information in the public
Nadja Belova, Marc Stuckey, Ralf Marks & Ingo Eilks ........................................................................... 185

Chapter 11: Making chemistry education relevant through mass media
Shu-Nu Chang Rundgren & Carl-Johann Rundgren ............................................................................. 205

Chapter 12: Learning about relevance concerning cultural and gender differences in chemistry education
Rachel Mamlok-Naaman, Simone Abels & Silvija Markic ..................................................................... 219

Chapter 13: Science-technology-society as a feasible paradigm for the relevance of chemistry education in emerging countries
Andoni Garritz, Bruno Ferreira dos Santos & María Gabriela Lorenzo ................................................. 241
CONTENTS

SECTION 3: HIGHLIGHTING THE VOCATIONAL AND ECONOMIC DIMENSION OF RELEVANT CHEMISTRY EDUCATION

Chapter 14: Understanding the change toward a greener chemistry by those who do chemistry and those who teach chemistry
George M. Bodner .................................................................................................................. 263

Chapter 15: Learning from and about industry for relevant chemistry education
Avi Hofstein & Miri Kesner .................................................................................................. 285

Chapter 16: The role of cooperative and work-integrated education in chemistry career clarification
Richard K. Coll .................................................................................................................... 301

Chapter 17: Innovation and employability: Moving beyond the buzzwords - a theoretical lens to improve chemistry education
Jan Alexis Nielsen & Henriette Tolstrup Holmgaard .............................................................. 317

SECTION 4: RELEVANT CHEMISTRY EDUCATION IN NON-FORMAL, INFORMAL AND TEACHER EDUCATION

Chapter 18: Relevance of non-formal education in science education
Sakari Tolppanen, Jenni Vartiainen, Veli-Matti Ikaivalo & Maija Aksela ......................... 335

Chapter 19: Using informal learning experiences to enhance student learning outcomes in chemistry
Sandhya D. Coll & David Treagust ....................................................................................... 355

Chapter 20: Professional development of chemistry teachers for relevant chemistry education
Muhammad Hugerat, Rachel Mamlok-Naaman, Ingo Eilks & Avi Hofstein ....................... 369

Index .................................................................................................................................... 387
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, etc.
meaningfulness, usefulness, and motivation (for more details see Stuckey, Hofstein, Mamlom-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; Knamiiller, 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 Knamiiller (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, Eijkellhof 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.

Stuecky 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](image-url)
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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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
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, Mamlak-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

<table>
<thead>
<tr>
<th>Category of big ideas in chemistry</th>
<th>Example of a big idea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contextual big idea</td>
<td></td>
</tr>
<tr>
<td>· General</td>
<td>· Chemistry for sustainability</td>
</tr>
<tr>
<td>· Specific</td>
<td>· Ozone layer chemistry and effects</td>
</tr>
<tr>
<td>Conceptual big idea</td>
<td></td>
</tr>
<tr>
<td>· Of chemistry</td>
<td>· Bonding; chemical equilibrium</td>
</tr>
<tr>
<td>· About chemistry</td>
<td>· Nature and methods of chemistry</td>
</tr>
</tbody>
</table>

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
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 exploratory 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

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

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**

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

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)

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

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” (Sjöberg & 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)

<table>
<thead>
<tr>
<th>Chemistry topic from the Swedish project</th>
<th>Relevance for 372 students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Most</td>
</tr>
<tr>
<td>Biochemistry</td>
<td>56%</td>
</tr>
<tr>
<td>Organic chemistry</td>
<td>46%</td>
</tr>
<tr>
<td>Atomic structure</td>
<td>36%</td>
</tr>
<tr>
<td>Acids &amp; bases</td>
<td>30%</td>
</tr>
<tr>
<td>Chemical analysis</td>
<td>26%</td>
</tr>
<tr>
<td>Chemical calculations &amp; stoichiometry</td>
<td>23%</td>
</tr>
<tr>
<td>Chemical bonding</td>
<td>20%</td>
</tr>
<tr>
<td>Energy/enthalpy</td>
<td>18%</td>
</tr>
<tr>
<td>Oxidation &amp; reduction</td>
<td>18%</td>
</tr>
<tr>
<td>Chemical equilibrium</td>
<td>17%</td>
</tr>
</tbody>
</table>

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.

REFERENCES


THE BIG IDEAS IN CHEMISTRY


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