Teaching Chemistry – A Studybook
A Practical Guide and Textbook for Student Teachers, Teacher Trainees and Teachers

Ingo Eilks
University of Bremen, Germany

and

Avi Hofstein (Eds.)
Weizmann Institute of Science, Israel

This book focuses on developing and updating prospective and practicing chemistry teachers’ pedagogical content knowledge. The 11 chapters of the book discuss the most essential theories from general and science education, and in the second part of each of the chapters apply the theory to examples from the chemistry classroom. Key sentences, tasks for self-assessment, and suggestions for further reading are also included. The book is focused on many different issues a teacher of chemistry is concerned with. The chapters provide contemporary discussions of the chemistry curriculum, objectives and assessment, motivation, learning difficulties, linguistic issues, practical work, student active pedagogies, ICT, informal learning, continuous professional development, and teaching chemistry in developing environments.

This book, with contributions from many of the world’s top experts in chemistry education, is a major publication offering something that has not previously been available. Within this single volume, chemistry teachers, teacher educators, and prospective teachers will find information and advice relating to key issues in teaching (such as the curriculum, assessment and so forth), but contextualised in terms of the specifics of teaching and learning of chemistry, and drawing upon the extensive research in the field. Moreover, the book is written in a scholarly style with extensive citations to the literature, thus providing an excellent starting point for teachers and research students undertaking scholarly studies in chemistry education; whilst, at the same time, offering insight and practical advice to support the planning of effective chemistry teaching. This book should be considered essential reading for those preparing for chemistry teaching, and will be an important addition to the libraries of all concerned with chemical education.

- Dr Keith S. Taber
  (University of Cambridge; Editor: Chemistry Education Research and Practice)

The highly regarded collection of authors in this book fills a critical void by providing an essential resource for teachers of chemistry to enhance pedagogical content knowledge for teaching modern chemistry. Through clever orchestration of examples and theory, and with carefully framed guiding questions, the book equips teachers to act on the relevance of essential chemistry knowledge to navigate such challenges as context, motivation to learn, thinking, activity, language, assessment, and maintaining professional expertise. If you are a secondary or post-secondary teacher of chemistry, this book will quickly become a favorite well-thumbed resource!

- Professor Hannah Sevian
  (University of Massachusetts Boston)
Teaching Chemistry – A Studybook

A Practical Guide and Textbook for Student Teachers, Teacher Trainees and Teachers

Edited by

Ingo Eilks
*University of Bremen, Germany*

and

Avi Hofstein
*Weizmann Institute of Science, Israel*
CONTENTS

Introduction v

Ingo Eilks & Avi Hofstein

1. How to allocate the chemistry curriculum between science and society
   Ingo Eilks, Franz Rauch, Bernd Ralle & Avi Hofstein 1

2. How to outline objectives for chemistry education and how to assess
   them
   Yael Shwartz, Yehudit Judy Dori & David F. Treagust 37

3. How to motivate students and raise their interest in chemistry education
   Claus Bolte, Sabine Streller & Avi Hofstein 67

4. How to balance chemistry education between observing phenomena
   and thinking in models
   Onno de Jong, Ron Blonder & John Oversby 97

5. How to deal with linguistic issues in chemistry classes
   Silvija Markic, Joanne Broggy & Peter Childs 127

6. How to learn in and from the chemistry laboratory
   Avi Hofstein, Mira Kipnis & Ian Abrahams 153

7. How to organise the chemistry classroom in a student-active mode
   Ingo Eilks, Gjalt T. Prins & Reuven Lazarowitz 183

8. How to promote chemistry learning through the use of ICT
   Yehudit Judy Dori, Susan Rodrigues & Sascha Schanze 213

9. How to benefit from the informal and interdisciplinary dimension of
   chemistry in teaching
   Richard K. Coll, John K. Gilbert, Albert Pilot & Sabine Streller 241

10. How to keep myself being a professional chemistry teacher
    Rachel Mamlok-Naaman, Franz Rauch, Silvija Markic & Carmen Fernandez 269
CONTENTS

11. How to teach science in emerging and developing environments 299
   Carmen Fernandez, Jack Holbrook, Rachel Mamlok-Naaman & Richard K. Coll

Contributors 327

Index 333
INTRODUCTION

Chemistry is an essential basis for many facets of our everyday lives, and has many unforeseen potential benefits for our future. An understanding of chemistry allows us the opportunity to make sense of, and explain the world around us. It develops basic knowledge of how to live in this world, to deal with the issues of daily life and how to make decisions concerning our actions as individuals. Examples are: how food changes when we cook it, how cleaning works and which cleaner to choose for which purpose, how materials are produced and how we can use them with respect to their different properties, the functioning of medicine, vitamins, supplements, and drugs, or understanding potentials and risks of many modern chemistry related products and technologies.

A lot of chemistry-related topics are essential to our lives and are also fundamental to the society in which we and our students operate. For example responsible use (and consumption) of energy resources, guaranteeing sufficient and healthy nutrition, securing sustainability in drinking water supply, framing sustainable industrial development, or dealing with the challenges of climate change. Clearly, these developments are important to all citizens who live and operate in a modern society and eventually (in the future) they will be asked to critically reflect upon these issues, to contribute to societal debate related, and to make important scientifically-based decisions. These reflections and decisions will be made individually or in groups within the society in which we live and operate.

Chemistry also offers many career opportunities. Chemistry education should give students guidance regarding potential future employment in chemistry related jobs. However, the career opportunities that a good grounding in chemistry can provide are not restricted to chemical industry. Understanding chemistry is necessary for working in almost all the other sciences such as biology, archaeology, geology, material sciences, engineering, environmental sciences, and medicine. Students opting for any of these career fields need good knowledge in chemistry and about current trends in chemistry. The subject is not just important for careers within the field of science and engineering, but also for those working in law, economy or trade, who often deal with the issues of chemistry and its relationship to ecology, economy, or society. In addition, those working in these fields could benefit from good chemistry education on high school level.

Finally chemistry as a science offers unique opportunities for learning about how science works and about the interaction of science, life and society. Learning in chemistry allows for the development of a lot of general skills, e.g. problem-solving, thinking in models, being sensitive to and aware of dangers and hazards, for environmental protection, or understanding how science contributes to society’s sustainable development. In this way chemistry has the potential to contribute to developing general educational skills. Some of these skills do overlap with the other sciences, some are even beyond all the sciences, but some of them are also unique to chemistry.
From all these reasons, we assert that chemistry is a subject that should be taught in the best way possible to all students at high school level. It should not be limited or solely oriented towards those few students intending to embark in the future on an academic career in chemistry. Chemistry is essential for allowing all students a thorough understanding the world around them, to enable them to contribute in societal debate about science and technology related issues, but also for offering career opportunities in the most effective and broadest way possible. Unfortunately, throughout the history of chemistry education many chemistry education programs failed to achieve many of these rather demanding goals.

A book to support reform towards modern chemistry teaching

In recent years, there has been a wide spread support around the world for reforming science education in general and chemistry teaching in particular. The need for scientifically literate citizens on one hand and reducing the shortage in personal interested in careers in science and engineering on the other hand are the key goals for this reform. In the beginning of the 21st century the need in both fields was supported by several comprehensive reports regarding the state of science education in many countries, e.g., in the USA by the John Glenn Committee in the position paper Before it is too late in 2000, or in Europe in Beyond 2000 by Robin Millar and Jonathan Osborne, or Science Education in Europe: Critical Reflections by Jonathan Osborne and Justin Dillon in 1998 and 2008 respectively. These reports suggest that many chemistry programmes all over the world and their related pedagogies are inadequate for sufficiently meeting both of these challenges.

In addition, in these reports, and also based in educational research, it is a commonly held belief that the teacher is one of the most important factors for effective and sustainable student learning. It is nearly unanimously agreed, that the teachers can have a tremendous impact on students’ understanding, performances, interest, and motivation. Based on many years of research and experiences obtained from the educational field it is suggested that proper training of teachers both in the pre-service phase and continuous professional development as part of in-service training could have the potentially greatest impact on the way chemistry is taught and as a result the way it is learned and perceived by the students. That is why nearly all of the reports above call upon the vital need to initiate reform under inclusion of evidence and theory-based innovations in pre-service teacher education as well as intensive and comprehensive long-term professional developments of the chemistry teachers. Thus, this book focuses on the application of educational research evidence and theory related to the learning of chemistry into chemistry teacher education in a comprehensive and practice-friendly way.

This book does not focus on all the various kinds of knowledge a teacher needs for effective chemistry teaching. The premise behind this book is to help to develop the (prospective) teachers’ PCK, their Pedagogical Content Knowledge related to the field of chemistry education.
The idea of investing in the PCK of the teachers was developed in the late 1980s by Lee S. Shulman. He described PCK as the educational knowledge that is developed by teachers to help others to learn in a specific domain of subject matter knowledge, in our case in chemistry. He differentiated the domain-specific educational knowledge (PCK) from the pure subject matter knowledge (the facts and theories of chemistry) and the general pedagogical knowledge (the theories about learning in general).

More applicable to science teaching Magnusson, Krajcik, and Borko in 1999 defined PCK to include five components (adopted from general science teaching to chemistry teaching):

- Orientation towards chemistry teaching to include goals for and approaches to teaching chemistry
- Knowledge of the chemistry curriculum
- Knowledge of chemistry instructional techniques (pedagogy)
- Knowledge of assessment methods in chemistry
- Knowledge of students’ understanding of chemistry

(For more details about the works of Magnusson, Krajcik, and Borko and the references therein, see Chapter 10).

Although the focus of this book is to aid the reader to update and develop their PCK in chemistry education, it is not possible to discuss PCK in isolation from the knowledge of general education and it will be not be coherent or comprehensible if it is detached totally from the chemistry related subject matter. That is why all of the chapters in this book start from or refer to ideas from general educational theory and are illustrated by examples from the chemistry classroom focusing on different aspects of chemistry.

With this goal in mind, a group of 27 scholars in chemistry and science education were involved in writing 11 chapters to support studying the basics of PCK in chemistry education. All of the authors are chemistry and science educators stemming from 10 different countries all over the world. Most of them have a rich background in the process of enhancement of chemistry teachers’ professionalism both in the pre- as well as the in-service education phases of the chemistry teachers’ career. The reader will find information about the authors’ backgrounds and expertise in the end of the book.

The content and the chapters

The aim of the book is to present the essential knowledge bases that chemistry and science education research provides in a way that a chemistry teacher can make use from. Clearly, the book is not about what research wants to tell us, but what a chemistry teacher needs to know. That is why this book is not a review of all theories and research findings available, but a selection of the most prominent and important issues a chemistry teacher is faced with in her or his daily practice.

Nevertheless, the focus of this book is in line with modern educational theories and current reform efforts in chemistry education worldwide. These reforms attempt to change the way chemistry is taught (and learned). For example, in the
1960s and early 1970s most of the programmes in chemistry were predominantly based on the conceptual approach to chemistry (the structure of the discipline approach), current programmes of chemistry are primarily based on the philosophy that the curriculum should place more emphasis on students’ interests and motivation and also societally relevant issues and contexts. This movement was driven by two ideas. The first was the finding that embedding chemistry learning in situations meaningful to the learners makes content learning more sustainable. The other considers using chemistry learning as a vehicle to educate the learners, utilising the approach of *education through chemistry* as part of the preparation of literate citizens rather than the traditional approach of solely transmitting *chemistry through education* to prepare the learners for potential further education in chemistry at the university level.

In the last 60 years a substantial body of research on learning and teaching chemistry was accumulated as a resource for developing pre- and in-service teachers’ PCK. Inspired by the constructivist learning theory, changes were derived and researched to shift chemistry education from rote memorisation of chemical facts and theories, towards learning for meaningful understanding. For example, learning should become embedded in meaningful contexts or originating from socio-scientific issues. It should originate from students’ interests to raise their motivation. It should be based on clearly reflected objectives and assessments and relates to potential misconceptions, linguistic issues in learning, and the growing heterogeneity in the chemistry classroom. Modern pedagogies of chemistry learning should encompass student-centred activities (as opposed to teacher centred ones). They should incorporate inquiry-based approaches through student laboratory work, cooperative learning methods, and the support of ICT for enhancing achievement. These ideas and theories should drive both formal and informal chemistry learning, be part of teacher in-service education, and take place in all educational systems independent of the level of development. Taking these arguments into account we have the structure of the book.

Every aspect (mentioned above) led to a chapter in the book. Each chapter makes an effort to respond to one of the general issues in the teaching of chemistry. It is based on the underpinnings of educational theory, covers the different facets of the issue, and is illustrated by several examples and suggestions from good chemistry classroom practice. This resulted in 11 chapters of the book, which are focusing on the following questions and issues:

– *How to allocate the chemistry curriculum between science and society:* This chapter deals with the issue related to the chemistry curriculum development and implementation. Ingo Eilks, Franz Rauch, Bernd Ralle and Avi Hofstein explain which potential lanes chemistry education can take, applying different orientations of the curriculum. A range of curricular approaches are discussed focusing for example on whether to better structure the curriculum using the theories or history of chemistry, or to orient chemistry teaching employing everyday life contexts or socio-scientific issues.
INTRODUCTION

- **How to justify formal chemistry education, to outline its objectives and to assess them:** This chapter deals with the learning progression and assessment. David Treagust, Yael Shwartz and Yehudit Dori give insight into what is meant by helping students to become chemically literate. They give guidance where to derive from, how to structure learning objectives, and how to assess them.

- **How to motivate students and raise their interest in chemistry education:** This chapter is about questions of motivation and interest. Claus Bolte, Sabine Streller and Avi Hofstein clarify the different concepts of motivation, interest and attitudes. They outline what the chemistry teacher can do in order to make chemistry education more motivating to the learners.

- **How to balance chemistry education between phenomena and thinking in models:** This chapter deals with the question of potential students’ misconceptions and the learning difficulties which are typical to chemistry teaching. Onno de Jong, Ron Blonder and John Oversby sensitise and guide the reader through the issues that might occur due to the difficulties surrounding the thought processes involved in chemistry, moving between the macroscopic world, the world of atoms and particles, and its related explanations using scientific models.

- **How to deal with linguistic issues and heterogeneity in the chemistry classroom:** This chapter deals with the important issue of language in chemistry learning. Silvija Markic, Joanne Broggy and Peter Childs discuss the general importance of language for any kind of learning. In addition, they also make an attempt to address the particular issues of language and formal chemical language which are important for successfully learning chemistry.

- **How to learn in and from the chemistry laboratory:** This chapter characterises the laboratory as a unique place for learning chemistry. Avi Hofstein, Mira Kipnis and Ian Abrahams critically reflect upon under which conditions operating in the chemistry laboratory offers opportunities for effective learning in chemistry education and introduce to the idea of inquiry-based science education.

- **How to organise a classroom in a student-active mode:** This chapter focuses the methods of teaching. Ingo Eilks, Gjalt Prins and Reuven Lazarowitz explain the importance of student-activity, interaction and cooperation for effective learning through different respective pedagogies and examples.

- **How to promote chemistry learning through the use of ICT:** The chapter is about the implementation of modern information and communication technology to improve chemistry learning. Yehudit Dori, Sascha Schanze and Susan Rodrigues provide insights into the theory of multimedia supported learning and how chemistry education can benefit from using modern technologies.

- **How to benefit from the informal and interdisciplinary dimension of chemistry in teaching:** This chapter opens school chemistry teaching beyond the classroom. Richard Coll, John Gilbert, Albert Pilot and Sabine Streller explain how school chemistry teaching can be enriched by learning in informal settings, like museums, industry visits, afternoon workshops in research laboratories, or just through television and print media.
How to keep myself being a professional chemistry teacher: This chapter makes the reader cognisant of the fact that teacher learning is a lifelong enterprise. Rachel Mamlok-Naaman, Franz Rauch, Silvija Markic and Carmen Fernandez explain why it is important to invest in teachers’ continuous professional development. They also give examples of promising strategies and well working models.

How to teach chemistry in emerging and developing environments: Finally, this chapter acknowledges the working conditions of chemistry teachers in the diverse world. Carmen Fernandez, Jack Holbrook, Rachel Mamlok-Naaman and Richard Coll and provide many ideas and offer access to resources describing how student-active and successful chemistry teaching can be provided even if the resources and working conditions for the teachers are limited.

The target audience and the idea of a studybook

As one can see from the title, this book is called a studybook and not a handbook. Thus, our target readers are not researcher’s per-se. The target audience, for whom the book was written for are the student teachers of chemistry, at both undergraduate and graduate level, prospective teachers in courses for chemistry teaching certificates, and practicing teachers who are interested in updating (and enhancing) their knowledge related to chemistry teaching. Therefore, the book provides prospective chemistry teachers in their pre-service education and practicing teachers as part of their in-service training with up-to-date background and professional experiences supporting their work as high school chemistry teachers in both lower and upper secondary school levels. But, we also hope the book will offer help and support to lecturers in chemistry education and professional development providers who are planning and executing their didactical (pedagogical) courses.

The structure of the books’ chapters

The book consists of many key elements related to the current (up-to-date) pedagogical aspects of teaching and learning chemistry. A lot of effort was made to present the readers with ideas, activities, and instructional approaches based on valid and reliable research-based evidence. However, as opposed to many handbooks that exist, we did not attempt to present a comprehensive review of the literature. The authors of the various chapters made their utmost effort to make a selection of theoretical essays and research-based articles that will be accessible and applicable to most of the prospective teachers, in-service teachers, and to their respective training and professional development providers.

Every chapter is thought to provide an easy to read and concise overview regarding the essentials of the theoretical (research-based) background of the various issues in chemistry teaching. In all the chapters the theory is followed by a practical section that provides the readers with practical ideas for more effective classroom practice. An attempt is made in all chapters to apply the theory (of the
1st part) to the practice (in the 2nd part) and provide illustrative examples for theory-driven practice in chemistry teaching. Additionally, the end of every chapter offers a summary of the most essential messages provided in the form of key sentences. The reader might use these in respective tasks for self-assessment, or to further enrich his or her knowledge by following selected ideas for further reading and a list of relevant websites.

We hope the book will help in bringing educational theory into the classrooms via the chemistry teachers worldwide more thoroughly. We wish the readers enjoyment and good luck in applying the theories and examples in their pedagogical interventions. In addition, we also hope chemistry education research helps via this way will contribute reform in chemistry teaching for more successful chemistry learning of our students in the future.

*We thank Dr. Sarah Hayes and Rita Fofana for their great help during the editing process of this book.*

Ingo Eilks and Avi Hofstein
1. HOW TO ALLOCATE THE CHEMISTRY CURRICULUM BETWEEN SCIENCE AND SOCIETY

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

THEORETICAL BASIS

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

(John Gilbert, 2006, p. 958)

Preparing future scientists vs. science education for all

When reviewing chemistry and science curricula from the 1960s and 1970s one can see that at that time the main goal of science curricula in general, and chemistry curricula in particular, was to give a limited portion of students a solid foundation in science to recruit and prepare these few students for future careers in science, engineering, or medicine. The results were that science curricula mainly focused on the learning of pure chemistry and were structured analogous to chemistry textbooks from the university. By the end of the day, chemistry was
considered by a majority of students as being a subject for only a very few intrinsic motivated students (see Chapter 3) and less connected to their life and interests.

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

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

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

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

interlinking of knowledge and social practice through establishing a need (relevant in the eyes of students), identifying the motives (wanting to solve
scientific problems and make socio-scientific decisions) leading to activity constituted by actions (learning in school towards becoming a scientifically literate, responsible citizen). (Holbrook & Rannikmäe, 2007, p. 1353)

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

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

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

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

- **Relevance for the individual**: meeting students’ curiosity and interest, giving them necessary and useful skills for coping in their everyday life today and in future, or contributing the students’ intellectual skill development.
- **Relevance for a future profession**: offering orientation for future professions, preparation for further academic or vocational training, or opening formal career chances (e.g. by having sufficient courses and achievements for being allowed to study medicine).
Relevance for the society: understanding the interdependence and interaction of science and society, developing skills for societal participation, or competencies in contributing society’s development.

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

The idea of the curriculum emphases

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

... a coherent set of messages about science (rather than within science).

Such messages constitute objectives which go beyond learning the facts, principles, laws and theories of the subject matter itself – objectives which provide answers to the student question: Why am I learning this? (Roberts, 1982, p. 245)

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

More recently, Van Berkel (2005) tried to update and reflect the idea of the curriculum emphases with respect to more recent curricula and with focus of the domain of chemistry education. Van Berkel refined the original seven emphases into three more general emphases, or one might say general aims in most chemistry curricula (Table 2). These three basic emphases were found by Van Berkel to represent most chemistry curricula of today.
### Table 1. The curriculum emphases on science by Roberts (1982) and illustrations with the focus on chemistry

<table>
<thead>
<tr>
<th>Curriculum Emphases</th>
<th>Description</th>
<th>Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Everyday coping</td>
<td>Science is presented as a way to understand natural or technical objects and events of everyday importance and relevance.</td>
<td>Learning chemistry facilitates the understanding of the function e.g. of detergents, fuels, or fertilizers.</td>
</tr>
<tr>
<td>Structure of science</td>
<td>The curriculum focuses the understanding of how science functions as an intellectual enterprise, e.g. the interplay of evidence and theory, the adequacy of a scientific model, or the theory development in science.</td>
<td>Learning is about e.g. bonding theory as a distinction principle between different kinds of matter, the difference between inorganic, organic and physical chemistry, or the development of the theory of atomic structure and the periodic system of the elements.</td>
</tr>
<tr>
<td>Science, technology and decisions</td>
<td>Science and technology are distinguished, and the difference from value-laden considerations in personal and societal decision making about scientific issues in everyday life is dealt with.</td>
<td>Socio-scientific issues, e.g. the use of bio-fuels, are not only dealt with concerning their scientific and technological background, but also ethical and societal values of their use and consequences to society are reflected.</td>
</tr>
<tr>
<td>Scientific skill development</td>
<td>The curriculum aims on the competence in the use of processes that are basic skills to all science.</td>
<td>General methods of solving problems and applying specific strategies and techniques from chemistry are dealt with.</td>
</tr>
<tr>
<td>Correct explanations</td>
<td>The curriculum stresses the “products” from science as accepted tools to correctly interpret events in the world.</td>
<td>Chemistry is offering accepted theories, like heat absorption in gases, to explain the greenhouse effect.</td>
</tr>
<tr>
<td>Self as explainer</td>
<td>The curriculum focuses the character of science as a cultural institution and as one of man’s capabilities.</td>
<td>Growth of scientific knowledge is explained as a function of human thinking in a specific era and within cultural and intellectual preoccupations, e.g. along the change in the different atomic models in the early 20th century.</td>
</tr>
<tr>
<td>Solid foundation</td>
<td>The role of science learning is to facilitate future science instructions.</td>
<td>Secondary chemistry should be organized to best prepare the students for later studying chemistry courses in the university.</td>
</tr>
</tbody>
</table>
Table 2. Refined curriculum emphases by Van Berkel (2005). Adapted from Van Driel, Bulte and Verloop (2007)

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

Basic orientations of the chemistry curriculum

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

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

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

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

- **History of science (chemistry) orientation**: The history of science is used to learn scientific content as it emerged in the past, but also to allow learning about the nature of chemistry and its historical development in the means of the KDC curriculum emphasis. Lesson plans are often planned along episodes from the history of chemistry.

- **Everyday life orientation**: Questions from everyday life are used to get an entry into the learning of chemistry. The approach is chosen so that learning chemistry has a meaning for the student. The student should feel a need to know about chemistry to cope with his life. E.g., the use of household cleaners is taken as a context for approaching acid-base-chemistry. This orientation is not easily connected to Van Berkel’s curriculum emphasis. In most cases it is directed to FC, but with a broader view it can include also CTS.

- **Environmental orientation**: Environmental issues are used to provoke the learning of science behind the issue, but also about questions of environmental protection. Examples can be lesson plans about clean drinking water, air pollution, or acidic rain. Here we can assume the same curriculum emphasis as for the everyday life orientation, although environmental issues more thoroughly ask for reflection in the CTS means.

- **Technology and industry orientation**: Developments from chemical technology and industry are dealt with in order to learn about chemistry and its application. The teaching in a broader view focuses about the interplay of science and technology within society. E.g. crude oil distillation or the industrial production of important metals are used as issues for chemistry lesson plans. Here the focus is clearly towards the CTS emphasis.

- **Socio-scientific issues orientation**: Socio-scientific issues form the starting point of chemistry learning, allowing the students to develop general educational skills to prepare them to become responsible citizens in future. Examples are the debate around climate change or effects in the use of bio-fuels for economy, ecology and society. This orientation is the most explicit CTS-type approach.

“Knowledge Development in Chemistry”-oriented science curricula

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

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

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

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

From “Fundamental Chemistry” driven curricula to context-based learning

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

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

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

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

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

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

A context must provide a coherent structural meaning for something new that is set within a broader perspective. These descriptions are consistent with the function of ‘the use of contexts’ in chemical education: students should be able to provide meaning to the learning of chemistry; they should experience their learning as relevant to some aspect of their lives and be able to construct coherent ‘mental maps’ of the subject. (Gilbert, 2006, p. 960)
In order to place a greater structure on context-based chemistry education, Gilbert (2006) considered a context to be a focal event and discussed four characteristics for any topic to become a context for chemistry education. Gilbert also discussed four general features of the use of contexts in chemistry education, to make clear what the vision of context-based chemistry education should look like (see also Table 3):

- **Context as a direct application of concepts**: An application is operated to illustrate a science concept’s use and significance. Topics are chosen from the presumed personal/social everyday life of the students to which the concepts of chemistry are taught as abstractions. The concepts are then applied so that the students understand the applicability of the concept. This approach is strictly about how the concepts are used in the applications, almost as an afterthought, to the end of the theoretical treatment of concepts and often without a consideration of their cultural significance. As a post-hoc illustration, it is only an attempt to give meaning to a concept after it has been learnt and is therefore hardly meets the idea of situated learning.

- **Context as reciprocity between concepts and applications**: In this approach, applying contexts affects the meaning attributed to the concepts. Viewing concepts from different perspectives (the scientist, the engineer, the politician) implies different meanings for one concept. This model provides a better basis for context-based chemistry education than the first one, although there is no obvious need for students to value the setting as the social, spatial, or temporal framework for a community of practice. But the behavioral environment may be of higher quality, dependent on the teacher’s understanding of the setting being used. The risk is that students do not see the relationship between a certain problem and why they should use some chemistry to deal with it, because the context of an expert does not automatically become a context of the learner.

- **Context provided as personal mental activity**: A specific person fixed in time and space who was seeking to explain a specific topic using chemistry is employed as context for learning chemistry. The model seems to be of greatest value when applied to cases of recent major events in chemistry. But, the use of this kind of events in chemistry will only be successful if students see the value of it. This is not always the case if the major events are historic, and as such took place long ago and have less meaning to the student. Also the chance for students to become actively involved is limited and the social dimension, through interaction within a community of practice, is missing.

- **Context as a social circumstance**: The social dimension of a context is put in focus as a cultural entity in society. This kind of context considers the importance of the context to the life of communities within society. Here, meaning-making can take place from two different perspectives, from a context as social surrounding or by a context as social activity. In science education, within this interpretation the context becomes intrinsic to student learning and fits most the ideas from situated learning and activity theory.
1. THE CHEMISTRY CURRICULUM

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

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Example: Chemistry of global warming</th>
<th>Consequences for context-based chemistry teaching</th>
</tr>
</thead>
<tbody>
<tr>
<td>A setting, a social, spatial, and temporal framework within which mental encounters with focal events are situated</td>
<td>Where, when, how is the focal event situated? The focal event is the general phenomenon of global warming, manifesting throughout the world in different ways.</td>
<td>The context must provide a setting of a social, spatial, and temporal framework for a community of practice. Participation in it should allow the students productive interaction and develop personal identities from the perspective of that community. The community of practice must provide a framework for the setting of focal events. The settings must clearly arise from the everyday lives of the students, or social issues and industrial situations that are both of contemporary importance to society.</td>
</tr>
<tr>
<td>A behavioral environment of the encounters, the way that the task(s), related to the focal event, have been addressed, is used to frame the talk that then takes place</td>
<td>What do people do in this situation; what actions do they take? Various measures to reduce the production of relevant gases are discussed, as are measures to remove those already in the atmosphere.</td>
<td>The learning task must clearly bring a specifically designed behavioral environment into focus. The type of activity engaged in, is used to frame the talk that then takes place. The task form must include problems that are clear exemplifications of chemically important concepts.</td>
</tr>
<tr>
<td>The use of specific language, as the talk associated with the focal event that takes place</td>
<td>In what language do people speak about their actions? The molecular structures of relevant gases are discussed, with a particular emphasis in a way that internal vibrations within the molecules lead to the observed effects.</td>
<td>Learners should be enabled to develop a coherent use of specific chemical language. Through the talk associated with the focal event, students should reach an understanding of the concepts involved. They should also come to acknowledge, that such specific language is a creation of human activity.</td>
</tr>
<tr>
<td>A relationship to extra-situational background knowledge</td>
<td>What is the background knowledge of those who act? The need for a general education about molecular structure and energy conversion is required.</td>
<td>Learners should perceive the relationship of any one focal event to relevant extra-situational, background knowledge. The students must be enabled to “resituate” specific language in order to address the focal event at hand. A vital source of focal events will be those with major public policy implications.</td>
</tr>
</tbody>
</table>
But, when trying to connect the chemistry curriculum along meaningful contexts, one has to be aware: Not every context considered by a teacher as being meaningful will necessarily work. A meaningful context for the teacher does not always signify that it is also meaningful to the student. Some examples of context-based science curricula from the US, the UK and Germany are discussed in the practice section below.

Curricula based on the “Chemistry, Technology, and Society” approach

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

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

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

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

Education for Sustainable Development (ESD) and the chemistry curriculum

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

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

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

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

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

Within the spider of topics (Figure 2), the segmentation refers to the triangle of sustainability: Two aspects are concerned with the environment, a further two with the economy and the final ones are related to society. By using the spider of topics when considering specific areas and lesson plans in chemistry education it can be evaluated at a glance to what degree the different aspects are incorporated in a teaching unit. Values are given to every aspect on a scale from 0 to 3. The greater
1. THE CHEMISTRY CURRICULUM

the effect of an issue on a category, the higher the resulting value. In the end the filled out space within the lines will give an idea of the potential of an issue within chemistry education for ESD and how it balances the different sub-domains. The reader may apply the “spider” towards some of the teaching examples discussed in the practice section below.

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

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

\[\text{Figure 2. Spider of topics for reflecting ESD teaching (Kyburz-Graber et al., 2010)}\]

\[\text{Figure 3. Spider of principles for reflecting ESD teaching (Kyburz-Graber et al., 2010)}\]
Hindering factors in curriculum innovation and the model of different representations of a curriculum

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

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

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

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

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

THE PRACTICE OF CHEMISTRY TEACHING

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

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

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

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

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

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

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

Nuffield Chemistry. The Nuffield Chemistry was developed in the UK in the 1960s (e.g. Atkin & Black, 2003). Prior to the Nuffield project, learning chemistry in the UK was characterised by the learning of a lot of independent facts. Textbooks looked like an encyclopaedia offering a lot of details. Learning chemistry by that time was mainly characterised by rote memorisation. Nuffield Chemistry aimed to shift chemistry teaching away from unconnected facts towards understanding the modern principles of chemistry, those principles that were regarded as being of fundamental importance. E.g., from just learning the names and properties of the elements, Nuffield chemistry aimed to develop an understanding of the systematic and trends within the Periodic Table of the Elements. Thus, learning chemistry was based firmly on three areas of students’ understanding: (i) The Periodic Table of the Elements to provide a unifying pattern for the diverse properties of elements and their compounds, (ii) the relationship between sub-microscopic structure (atomic and molecular) and the properties of chemicals, and (iii) the way in which energy transfers can determine the feasibility and outcomes of reactions.
In order to foster a better understanding of the role of the fundamental principles, the Nuffield curriculum presented chemistry as a subject of systematic knowledge by (i) a breakdown of the barriers between the traditional division of inorganic, organic and physical chemistry, (ii) an integration of facts and concepts, (iii) integrating theory and practical work, and finally (iv) the connection of ‘pure’ and ‘applied’ chemistry through the inclusion of topics from special areas such as food science, biochemistry, chemical engineering or metallurgy.

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

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

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

Later, CHEMStudy was developed as an addition to CBA, also focusing on those students with no further interest in chemistry studies beyond high school. CHEMStudy tried to reduce the volume of the syllabus by condensing the chemistry content to the most central principles. Also CHEMStudy, like in the
Nuffield example, tried to draw a concise picture of chemistry fitting to its basic theories, like atomic structure or bonding theory. The pedagogy of CHEMStudy was also based on integrating theory learning and laboratory work to give students a better idea of scientific inquiry. Unfortunately, these innovations suffered from lack of illustrations from everyday life and chemical industry, particularly when compared to the older textbooks in the US.

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

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

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

![Figure 4. A change in directions (Reid, 2000)](image_url)
Chemistry curricula base or focusing on the history of science (HOS)

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

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

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

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

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

Context-based chemistry curricula

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

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

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

Table 5. Contexts used in ChemCom

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

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

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

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

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

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

Table 6. Sketch from a Salters curriculum unit

<table>
<thead>
<tr>
<th>Activities</th>
<th>Chemical storyline</th>
<th>Chemical ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Writing the formulae of ionic compounds</td>
<td>Why is the sea so salty? – A story of smokers and solutions</td>
<td>Ions in solids in solution (precipitation and ionic equations)</td>
</tr>
<tr>
<td>Solutions of ions</td>
<td>The lowest point on earth</td>
<td>Concentrations of solution</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Atoms and ions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chemical bonding (using formulae)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ions and solids in solution (dissolving)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oxidation and reduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The p-block: group 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electronic structure, sub-shells and orbitals</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Writing an industrial case study – how best to</td>
<td>An industrial case study – how best to manufacture chlorine</td>
<td>The operation of chemical manufacturing process</td>
</tr>
<tr>
<td>manufacture chlorine</td>
<td></td>
<td>Raw materials</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Costs and efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plant location</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Health and safety</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Waste disposal</td>
</tr>
<tr>
<td>Which is the most cost-effective brand of bleach?</td>
<td>From atomic bombs to safer drinking water</td>
<td>Chemical bonding (bond polarity and electronegativity)</td>
</tr>
<tr>
<td>What do the halogens look like?</td>
<td></td>
<td>Forces between molecules: temporary and permanent dipoles</td>
</tr>
<tr>
<td>This liquid is dangerous</td>
<td></td>
<td>The p-block: Group 7</td>
</tr>
<tr>
<td>Reactions of halogens and halides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check your knowledge and understanding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finding the concentration of an acid solution</td>
<td>Hydrochloric acid – an industrial success</td>
<td>Concentration of solutions (titrations)</td>
</tr>
<tr>
<td>Manufacturing halogens and their compounds</td>
<td></td>
<td>Percentage of yield and atom economy (atom economy)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nucleophilic substitution reaction mechanism</td>
<td>Treasures of the sea</td>
<td>Halogenalkanes</td>
</tr>
<tr>
<td>How do halogenoalkanes differ in reactivity?</td>
<td></td>
<td>Percentage yield and atom economy (percentage yield)</td>
</tr>
<tr>
<td>Making of halogenalkane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check your knowledge and understanding</td>
<td>Summary</td>
<td></td>
</tr>
</tbody>
</table>
Chemie im Kontext (ChiK). Being inspired by the Salters project, the project Chemie im Kontext (ChiK) started in Germany in the 1990s. Three theoretical components underpin the philosophy of ChiK: an orientation on the concept of scientific literacy for all, the recognition of theories and evidence regarding motivation, and a thorough orientation on the theory of situated learning (Parchmann et al., 2006; Nentwig, Parchmann, Gräsel, Ralle, & Demuth, 2007). Even more so than Salters, ChiK is strongly built upon self-directed and cooperative forms of learning (see Chapter 7).

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

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

![Figure 5. Building up basic concepts from different contexts](image-url)
From the pedagogy, a lesson plan from ChiK is always subdivided into four stages (Table 7). In the first phase of contact the students are confronted with the context, e.g. table salt. Using most diverse materials, media and food for thought, the significance of context for everybody is illustrated. The ensuing phase of curiosity and planning is supposed to collect and structure the questions that arose in stage one in such a way that they can be addressed and answered appropriately within the third phase of elaboration. This stage aims to explore the students’ questions in such a way that the necessary chemical expertise is facilitated. On the other hand students recognise the connection to the context and their own questions and perceive chemistry as helpful and meaningful for them. Within the final phase the content is examined in more depth and networked to other knowledge, interrelations to previously discussed contexts and learned content take place. This phase aims at the promotion of establishing cumulatively the basic chemical principles.

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

<table>
<thead>
<tr>
<th>Phase of contact</th>
<th>Story: “Bread and salt – presents of the gods” Brainstorming on students ideas and prior-knowledge on the topic ‘table salt’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase of curiosity and planning</td>
<td>Structuring with mindmaps, collecting students’ questions, planning the work</td>
</tr>
<tr>
<td>Phase of elaboration</td>
<td>Learning at stations on the properties of table salt and ionic bonding</td>
</tr>
<tr>
<td>Phase of deepening and networking</td>
<td>Presentations with posters and experiments on the different aspects of table salt, networking the content with other knowledge, e.g. atomic structure and bonding</td>
</tr>
</tbody>
</table>

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

Socio-scientific issues based chemistry teaching

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

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

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

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

Marks and Eilks (2009) developed a whole set of this kind of lesson plans. All follow a joint educational model (Figure 6). Criteria for selecting such
controversial issues are discussed earlier in this chapter. But, the model also gives guidance for the pedagogy, e.g. by the use of authentic materials from newspapers, brochures, or TV and the use of student-active methods for learning the background science but also for learning about how chemistry is handled in society. Such methods can encompass role-play and business games. However, the writing of news-spots for a fictional TV-show on a controversial issue (see Chapter 7) or the mimicking of a consumer test (see next section) can also be examples. Another example in Table 8 on bioethanol usage is given for illustrating the different steps and the pedagogy.

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

**Education for Sustainable Development (ESD) and chemistry teaching**

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

The students read and analyse an authentic article from a political magazine reporting the growing use of bioethanol as fuels and critically mentioning potential side effects such as cutting down rain forests and a rise in food prices on the world market.

2. **Clarifying the chemistry background in a lab-environment**

The students learn about the structure of alcohols, fermentation, and the problems and benefits of the use of alcohols as fuels in cars, by using the cooperative mode of a jigsaw classroom in combination with a learning at stations lab.

3. **Resuming the societal debate**

A joint reflection leads to the understanding that the chemistry background might be sufficiently clear. But, the base for a political decision also will have to include consideration of ecological, economical and social effects.

4. **Discussing and evaluating different points of view**

A parliaments’ hearing is mimicked in a role play. The preparation and presentation explicates the different arguments and points of view of different stakeholders from within society.

5. **Meta-reflection**

A meta-reflection on the debate highlights the different roles of scientists, pressure groups and politicians, makes clear the complexity of the decision, and also shows how society is handling such decision making.

---

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

The lesson plan uses the debate about the extensive use of plastics in our current society. The benefits of plastics are mainly the cheap and practical use of plastics; this is confronted and examined in the context of the growing amounts of plastics waste in the environment and the social problems of exporting waste from the Western world to poorer countries. Taking into consideration the multi-dimensional effects of plastics usage, an evaluation is complex. The use of different sorts of conventional plastics, or the search for alternatives, like bioplastics from starch, have to be evaluated by many means, not only by looking at the practical dimension of synthesis and properties.
That is why the lesson plan goes beyond confronting the students with essential chemistry of polymer production, investigations of their properties or the synthesis of bio-plastics. The lesson plan operates a specific method to allow students to learn that an evaluation with respect to sustainability has to use and find a balance between different dimensions, i.e. the practicability and worth of its use, but also the economical, ecological and social effects of production, use and deposition. In this case the students mimic the work of a consumer test agency. The students have to find out about and negotiate the different dimensions and aspects that will influence the overall evaluation. The students have to decide how big the percentage value is in terms of how to weight each of the dimensions and what their influence on the overall evaluation should be. Those dimensions often conflict with each other. A change in the weighing might influence the result even more than a different value in one of the dimensions.

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

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

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

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

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

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

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

**SUMMARY: KEY SENTENCES**

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

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

ASK YOURSELF

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

HINTS FOR FURTHER READING


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


**RESOURCES FROM THE INTERNET**

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

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

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

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


**REFERENCES**


2. HOW TO OUTLINE OBJECTIVES FOR CHEMISTRY EDUCATION AND HOW TO ASSESS THEM

Chemistry education at the secondary level is usually warranted by two main justifications that seem somewhat contradicting – one is the attainment of chemical literacy for all future citizens and the other (and more traditional one) is to provide a preparatory course for future chemistry education at the university level. This chapter suggests a view of chemical literacy that goes beyond content and concepts in chemistry, and focuses also on higher-order thinking skills, attitudes and habits of mind, four levels of chemistry understanding, and appreciation of the role of chemistry in different contexts in life. In addition examples of different models for teaching chemistry are introduced including some recommendations of how to address the needs of heterogeneous populations. Finally, the role of assessment for learning and curriculum innovation is discussed.

THEORETICAL BASIS

Can chemistry, as a subject field, contribute to schooling of the +80% of learners in each age group who are most unlikely to study chemistry again after leaving school? (Peter Fensham, 1984, p. 200)

What are the general aims of formal chemistry education?

When preparing a lesson, every teacher sets objectives to be attained by teaching this lesson. A teacher may ask the following questions: What do I want my students to understand? Or: What are they supposed to be able to do as a result of learning? The same type of thinking about objectives or goals should be practiced when thinking about teaching chemistry in the classroom. For the past 50 years, and also in earlier times, a major discussion point for school science in general and chemistry in particular was what should be the focus of this education? The answers provided for this question dictate the practical objectives for school chemistry education, the curriculum and the goals for students’ and teachers’ assessment. This question is of concern for a broad spectrum of stakeholders in science education – namely policy makers, curriculum designers and, of course,
school teachers. It is especially relevant in an era in which standards and benchmarks for scientific literacy are set world-wide.

We may start from what is currently considered as formal education in chemistry and how this is best described. One of the findings from a curricular Delphi study on chemistry education in Germany by Bolte (2008) based on responses from teachers, students, educators, and scientists is that the main emphasis of chemistry teaching is still on chemistry topics rather than having a focus on scientific or chemical literacy. The learning of facts and theories is considered to be more the emphasis of formal chemistry education, rather than to enable students to understand the role of science/chemistry in their life, in society and to become able to participate in societal debate about developments connected to science and technology. A review of other studies and assessment of chemistry curricula in Australia, the USA, and Israel also has shown this to be the case, despite the rhetoric to have a populace with high levels of chemical literacy.

The interesting quote given above and raised more than 25 years ago by an eminent science/chemical education researcher, Peter Fensham, needs to be reflected in the foreground of these findings. The answer to this question is that chemistry studies in formal education in schools, as in all the other science disciplines, should address broader goals, especially attainment of scientific literacy for all students.

Justifying scientific/chemical literacy for all

The public need for scientific and chemical literacy for all students is justified in three ways:

– Economic and political reasons: This argument calls for public and political support of large investments in basic scientific and technological research. The future citizens need to be convinced that such investments will result in the well-being of humanity in general, and their nation in particular (Miller, 1983; Prewitt, 1983; Walberg, 1983; NRC, 1996).

– Practical-personal reasons: It is assumed that knowledgeable citizens would feel more confident and competent to cope with science-related issues in their daily life (Laugksch, 2000). The examples of such issues are endless: diet, smoking, safety, health and illness, cellular phones, genetic engineering of food, vaccines, medicines, etc..

– Cultural reasons relating to ideals, values, and norms: Science has shaped the western world’s view, and the scientific way of thinking is strongly connected to philosophy. Therefore, scientific literacy is regarded as contributing to the intellectual development of individuals, as well as a social tool that can defeat dogmas, superstitions, prejudice, magic, anti-science movements, etc. (Sagan 1996; Sjøberg, 1997).

The educational efforts to attain scientific literacy for all students led countries world-wide to publish national standards and benchmarks for scientific literacy for the general public (NRC, 1996, 2011; AAAS, 1993, 2001). These standards address some content ideas in chemistry and usually include the particulate nature...
of matter, structure of matter and its properties, or the principles and nature of chemical reactions. Naturally, chemistry studies that investigate the effect of these standards should address the new teaching goals and pedagogy, emphasising the chemical content ideas and nature of science.

**Attainment of chemical literacy**

A broader and more comprehensive view of the aim of chemistry education is provided by several theoretical studies aimed at defining ‘chemical literacy.’ In a study conducted in the UK, Holman (2002) suggested three domains toward a working definition of ‘chemical literacy’: Key chemical ideas, what chemists do, and chemical contexts. Holman called for curricula design addressing these three domains.

Another definition constructed as a collaborative work of chemistry education researchers, chemistry teachers, and scientists (Shwartz, Ben-Zvi, & Hofstein, 2006) suggested four domains for chemical literacy:

**Domain 1 – Chemistry as a scientific discipline.** Within this domain,

- Chemistry is an experimental discipline. Chemists conduct scientific inquiries, make generalisations, and suggest theories to explain the natural world.
- Chemistry provides knowledge used to explain phenomena in other areas, such as earth sciences and life sciences.
- Chemistry explains macroscopic phenomena and the structure of matter in terms of the microscopic or submicroscopic, symbolic, and process levels. (In the science education literature the terms microscopic and submicroscopic are mostly used interchangeably. In this book from here we will use the term sub-microscopic or submicro for the level of particles and atoms.)
- Chemistry investigates the dynamics of processes and reactions.
- Chemistry investigates the energy changes during a chemical reaction.
- Chemistry aims at understanding and explaining life in terms of chemical structures and the chemical processes of living systems.
- Chemists use a specific language. A literate person does not have to know how to use this language, but should appreciate its contribution to the development of the discipline (see Chapters 4, 5, and 6).

**Domain 2 – Chemistry in context.** The second dimension of chemical literacy is the ability to see the relevance and usability of chemistry in many related contexts:

- A chemically literate person acknowledges the importance of chemical knowledge in explaining everyday phenomena.
- A chemically literate person uses his/her understanding of chemistry in daily life, as a consumer of new products and new technologies, in decision-making, and in participating in a social debate regarding chemistry-related issues.
- Chemistry has a strong applicative aspect. A chemically literate person understands the relations between innovations in chemistry and sociological and cultural processes (the importance of applications such as medicines, fertilisers, and polymers) (see Chapter 1).
Domain 3 – Higher-order thinking skills. A chemically literate person is able to pose a question, and look for information and relate to it, when needed. He/she can analyse the loss/benefit in any debate (see Chapter 1).

Domain 4 – Affective aspects. A chemically literate person has impartial and realistic view of chemistry and its applications. Moreover, he/she expresses interest in chemical issues; especially in non-formal frameworks (such as a TV programme and a consumer debate) (see Chapter 9).

These ideas and domains can be introduced at various levels – a basic level aimed for general public understanding, and an advanced level aimed for those who choose chemistry as a major.

Attainment of chemical literacy is in-line with the central European tradition of Allgemeinbildung as the central objective of any formal or informal education. The term incorporates – education for ‘all’ persons, in all human capacities that we can recognise in our time and with respect to those general problems that concern our society. The goal is to educate the future citizens to be able to cope with societal challenges as responsible citizens, in a democratic society (Hofstein, Eilks, & Bybee, 2011) (see Chapter 1).

The main justification for teaching chemistry at the secondary level is therefore the attainment of chemical literacy for all future citizens. We conclude that chemical literacy is more than just pure chemical knowledge and concepts. Our goals are also that future citizens will understand the contribution of chemistry in various contexts, will develop higher-order thinking skills, and have critical but positive attitudes toward chemistry and its applications.

While this is an important and valuable goal one may ask: Is the more traditional goal of preparing future scientists totally irrelevant? On a practical level this question raises many other questions:

– In which ways would (or should) instruction be different when teaching for attainment of chemical literacy or for preparing future scientists?
– How does one teach if one has a heterogeneous population of students, some of whom would never become scientists and others who would consider doing so?
– In which ways would (or should) assessment be different when teaching for attainment of chemical literacy or for preparing future scientists?
– How would one recognise the underlying justifications of a written curriculum, so one can best choose learning materials for the students?

The following paragraphs address the last question, because selecting (or developing) an appropriate curriculum is a fundamental decision made by teachers.

Curriculum emphases as indicators of the curriculum justification

Gilbert and Treagust (2008) introduce another approach to justifying chemistry education by grouping aspects of the formal chemistry curricula that best serve the needs of society. They identified six basic ‘emphases’ (see Chapter 1) divided into two groups from the work of Roberts and Ostman (1998). Group A emphases are
concerned with the student as a person, a citizen, and an employee. Group B emphases are the interests of those who will study chemistry or related sciences to an advanced level.

Analysing these groups in more detail, group A emphases correlated with the definition of a scientifically literate citizen are: (a) Everyday coping which enables sense to be made of objects and events in everyday life, (b) self-as-explainer which deals with the processes by which chemical explanations are produced, (c) chemistry, technology, and decisions which deals with the way that chemical knowledge is reflected in technological innovations and with the social, political, and economic decisions that such innovations entail, and (d) correct explanations which are the conclusions so far reached by chemistry that are needed for the citizen to understand how the world-as-experienced works. Group B has two emphases: (a) chemistry skill development which is the development of chemical knowledge treated as if it involved the acquisition and use of a series of de-contextualised skills, and (b) structure of chemistry which provides an understanding how chemistry functions as an intellectual enterprise. It is assumed that group B emphases are more likely to address the needs of those students who would eventually embark on a scientific career. For a more comprehensive discussion of the idea of curriculum emphases connected to curriculum structures, see Chapter 1.

In terms of the development of chemical literacy (DeBoer, 2000), those emphasised in group A should be made available to all students so that they understand the macro type of representations when they encounter a ‘chemical phenomenon’ such as a solution, a colloid, or a precipitate. These emphases also call for an understanding of the microscopic type of representation so that learners can qualitatively explain the nature of the macro phenomena that they encounter and hence be able to answer the question: Why is it as it is?

Current trends that address group A emphases and create an appropriate curriculum for general education in chemistry are the context-based approach and the focus on socio-scientific issues in chemistry education. Context-based chemistry curricula developed in the USA (ChemCom), the UK (Salters chemistry), Germany (Chemie im Kontext), The Netherlands and elsewhere (Pilot & Bulte, 2006) illustrate that chemistry has meaning in the everyday world. Socio-scientific issues-based teaching tries to develop skills for active participation in societal discourse about developments related to chemistry (Marks & Eilks, 2009; Sadler, 2011). The mutual basis of all these curricular initiatives is the effort to introduce chemistry to the general public, in such a way that it would be both more interesting and more beneficial (Nentwig & Waddington, 2005). These approaches emphasise chemistry as a human activity and social endeavour. For some, the pedagogy is more based on situated learning, for others more on the goals of competence acquisition and thinking skills that will help students to cope with complex socio-scientific problems in the future.

The formal curriculum of group B serves the interests of those who will study chemistry or related sciences in greater depth. These students will need a more comprehensive understanding of the macroscopic and submicroscopic types of
representation than students learning in group A curriculum. The students studying group B curriculum will be required to understand the symbolic types of representation so that they can also provide quantitative explanations of phenomena and develop understanding of a chemical reaction and its mechanisms. The traditional contexts of chemistry education, often the contexts in which the ideas were originally discovered/invented, will be adequate if not necessarily inspiring. The use of contemporary ‘authentic research contexts’ is highly desirable here too.

If this argument for dividing emphases in chemistry education into two groups has any merit, then the structuring of the formal chemical curricula will need to deal with the interrelation between macroscopic and submicroscopic types for everybody whilst also dealing with a symbolic and process types with possible future chemistry or chemistry-related specialists. The realities of educational systems suggest that the group A emphases be addressed first, so that everybody learns about them, with the group B emphases coming later and only for those students who want to specialise in chemistry.

Organisation of chemistry in the formal school curriculum

In the book *Teaching chemistry around the world*, Risch (2010) asked authors from 24 countries to describe the status of chemistry education in their respective countries. A major aim of this survey was for authors to respond to the question: How do education systems handle the discrepancy between unpopularity of chemistry and its importance as a field of study? An outcome of the investigation was “to look out for better models and concepts in order to identify best-practice-models [for teaching]” (p. 9). Two of the core themes are that: (a) successful education systems have extensive selection procedures for students wanting to become chemistry teachers, and (b) some countries teach science as a single general subject while others teach the sciences as separate subjects, including chemistry, beginning in fifth, sixth or seventh grades.

One example where science is taught as a single general subject up until grade 10 is Australia. Chemistry (as well as other science disciplines) is not taught as a separate subject until grades 11 and 12. Several topics relating to chemistry that involve understanding of chemical phenomena and concepts to varying degrees are incorporated in the science curriculum in grade 8-10 within conceptual strands that include *Earth and Beyond*, *Energy and Change*, *Natural and Processed Materials* and a process-based strand, *Working Scientifically*. Recognising that students’ learning progresses at different rates, multiple levels of achievement are described for each strand, and student’s achievement is described by learning outcomes instead of a rigid syllabus content that teachers were expected to implement.

In Australia, chemistry is taught in the post-compulsory years (grades 11-12) with considerable consistency (85-95%) of the curriculum content common to all the states and territories. These topics are atomic structure, structure of materials, stoichiometry, quantitative chemistry, reactions and equations, thermochemistry, and organic chemistry. The chemistry content covered in grades 11 and 12 is
2. OBJECTIVES AND ASSESSMENT

defined in a syllabus issued by the education authorities of the states and territories. The objectives are geared towards enhancing students’ (a) knowledge, understanding, and intellectual skills in several areas in chemistry, (b) manipulative skills associated with laboratory work, while at the same time, having confidence in handling safe and dangerous chemicals, and (c) affective attitudes towards chemistry. Part of the rationale at this level is that chemistry education is the broader literacy intention to enable students to understand and interpret the chemistry of their surroundings and appreciate the impact of chemical knowledge and technology on society. Considering the curriculum emphases referred to above, the curriculum in grades 8-10 has more group A emphases than in grades 11-12; group B emphases are introduced in grade 10 with increasing attention in grades 11-12.

The meaning of relevance in the formal curriculum

The implicit pressure for greater ‘relevance’ is reflected in the current general requirement that science curricula should lead to scientific literacy for all students (DeBoer, 2000). In terms of chemistry, this might entail: understanding the nature of chemistry, its norms and methods, understanding how chemistry principles help explain every-day phenomena, understanding how chemistry and chemistry-based technologies relate to each other (Barnea & Dori, 2000; Dori & Sasson, 2008), and appreciating the impact of chemistry and chemistry-based technologies on society (Shwartz, Ben-Zvi, & Hofstein, 2006). Situating the scientific concepts in a relevant context provides a purpose for learning the science content itself and nevertheless helps students value the usefulness and plausibility of the scientific ideas. Also contextual knowledge is considered as increasing curiosity and motivation, as well as future possible utilization of knowledge (Fleming, 1998; Bennett & Holman, 2002).

For better comprehension, we provide two examples for the central and complicated role of relevance in the chemistry curriculum in two different educational models. The first is the IQWST middle-school curriculum developed in the US (Krajcik, Reiser, Sutherland, & Fortus, 2011) and the second is the advanced programme for chemistry majors in Israel.

Relevance in the IQWST model. The Investigating and Questioning our World through Science and Technology (IQWST) curriculum introduces physics, chemistry, biology, and earth science as separate but strongly related subjects already at the beginning of middle-school (grade 6, age 12-13). Each year the students learn four units – one of each discipline – in a context-based curriculum. Each unit is organized around an open-ended question, called a driving question, which provides a context that drives the learning of the unit’s key concepts (Shwartz, Weizman, Fortus, Krajcik, & Reiser, 2008). The chemistry units driving questions and the related scientific concepts are: “How can we smell things from a distance?” This unit introduces the particle nature of matter, states of matter and phase changes both on the macroscopic and submicroscopic level; “How can we
“make new stuff from old stuff?” engages students in making soap out of daily oils or fats and introduces chemical reactions; and the unit “Where do I get my energy from?” introduces chemical reactions in living systems focusing on cellular respiration and photosynthesis. The driving questions were chosen after questioning and interviewing middle-school students and their teachers. The investigation of each driving question branches and leads to other related questions. The curriculum sets a high level of inter and intra unit coherence, not only among the chemistry units but also with units from other subjects, especially regarding the development of scientific practices such as modelling or scientific reasoning.

Relevance in the Israeli advanced chemistry programme. While it is common to associate ‘relevance’ with a curriculum that aims at scientific literacy of the general public (see Chapter 1) we would like to illustrate a case in which relevance and students’ engagement sets the framework for learning post-compulsory (grades 11-12) chemistry. The advanced chemistry programme in Israel is taught in two levels: a basic level composed of three units – for chemistry majors, and an advanced five units – for honour students, who opt to choose science-related and engineering careers. Each level introduces different modules.

Until the 1980s, the traditional topics that were included in the basic (three units) old syllabus for the Israeli chemistry curriculum encompassed atomic structure, the periodic table of the elements, chemical bonds, metals, ionic and molecular compounds and their properties, stoichiometry, energy and chemical equilibrium, acids and bases, redox reactions, hydrocarbon compounds, and functional groups. The two advanced units included obligatory topics, such as thermodynamics and electrochemical cells, as well as one industry-related topic. Other optional topics were chosen by the teachers from a list, such as: polymers, carbohydrates, electrochemistry, and interaction between radiation and matter. Between the 1980s and the beginning of the 21st century, all the parts of the matriculation examination were given as paper and pencil test without any laboratory component. As a result of this assessment the laboratory was replaced by teachers’ demonstrations. The lack of laboratory activities affected students’ motivation and enjoyment of the subject and reduced the number of students who chose to study chemistry (Barnea, Dori, & Hofstein, 2010).

At the beginning of the 21st century, the syllabi of both the basic and the advanced courses were modified to stress more learning in context, real-world problems, and to foster scientific thinking skills, and less weight was put on content and quantitative chemistry. For example, a part of organic chemistry is taught in the new curriculum via a basic level (three) unit titled *Taste of chemistry* (Avargil, Herscovitz, & Dori, 2012; Herscovitz, Kaberman, & Dori, 2007). It is an interdisciplinary unit, which integrates basic chemical concepts and processes (such as lipids, carbohydrates and proteins, and their structure and function in our body) with nutritional, health and social aspects. Another example for the basic level (three units) is *Chemistry inside us* (Katchevitch, Ernst, Barad, & Rapaport, 2006), which introduces the traditional topics of reduction-oxidation
reactions and acids-bases in the context of specific physiological issues: What metal can be used to set a broken bone? How do antioxidants protect us? Other advanced (five) units include *Chemistry and the environment* (Mandler, Yayon, & Aharoni, 2011) which investigates two phenomena – water quality and global warming – while introducing analytic and spectroscopic chemistry, and *From nano-scale chemistry to microelectronics*, an advanced unit which introduces the uses of quantum mechanics in the micro-electronics industry (Dangur, Peskin, & Dori, 2009).

In these examples, for both the middle-school curriculum which is aimed for all students and the post-compulsory which is oriented toward advanced and chemistry majors, the relevance of what is being taught is a central curriculum organiser. It drives the learning of the chemical concepts and processes. Unlike traditional chemistry curricula in which the relevance of chemical knowledge for any application was left to the end of every chapter (if mentioned at all), not all teachers discussed it with their students, and it was not considered as an integral part of the formal syllabus and was not part of what was assessed in formal assessment.

Some issues regarding the relevance of school science to real life has to do with the question: Who should decide on the content and the appropriate context? Should the aspects relevant for any application be part of a formal syllabus or curriculum? What degree of freedoms should be left both for the teacher and the students to delve into aspects considered relevant to a specific classroom in a specific location? Another issue raised by Treagust (2002) was that having a locally relevant curriculum would lead to very different curricula in different parts of the world, and would make it difficult to compare achievements, or to transfer curricula from countries with ample resources to those without sufficient resources.

**The role of assessment for learning and curriculum innovation**

Data from the last three decades of research has shown that the majority of students come to science classes with pre-knowledge or beliefs about the phenomenon and concepts to be taught, and many develop only a limited understanding of science concepts following instruction (Duit & Treagust, 2003; see Chapter 4). Long-standing concerns about the nature and effectiveness of assessment practices in science have generally focused on the need to change the goals and outcomes of testing procedures. Osborne and Dillon (2008) noted that if science courses were to engage students in higher-order thinking, then students need to construct arguments, ask questions, make comparisons, establish causal relationships, identify hidden assumptions, evaluate and interpret data, formulate hypotheses and identify and control variables. For these researchers, the implementation of this cognitive curriculum implied a pressing research need to improve “the range and quality of assessment items used both to diagnose and assess student understanding of processes, practices and content of science” (p. 24).

Based on research with teachers, Barksdale-Ladd and Thomas (2000) identified five best practices in assessment: (a) providing feedback to help students improve
their learning (formative assessment), (b) conceptualising assessment as part of a student’s work, which can go into a working portfolio, (c) providing flexibility so that assessment does not dominate the curriculum, (d) ensuring that assessment informs instruction to help teachers improve their teaching, thereby ensuring student learning, and (e) using more than one measuring stick to assess students’ learning.

It is obvious that assessment that focuses on chemical content is not enough. This approach is demonstrated by the Program for International Student Assessment (PISA) coordinated by the Organisation for Economic Co-operation and Development (OECD). It focuses on 15-year-olds’ capabilities in reading literacy, mathematics literacy, and scientific literacy. PISA also includes measures of general or cross-curricular competencies such as problem solving. PISA emphasises functional skills that students have acquired as they are near the end of compulsory schooling (unlike PISA, The Trends In Mathematics and Science Studies (TIMSS) measure more traditional classroom content knowledge). At the highest level of science capabilities, students can consistently identify, explain and apply scientific knowledge and knowledge about science in a variety of complex life situations. They can link different information sources and explanations and use evidence from those sources to justify decisions. They clearly and consistently demonstrate advanced scientific thinking and reasoning, and they demonstrate willingness to use their scientific understanding in support of solutions to unfamiliar scientific and technological situations. Students at this level can use scientific knowledge and develop arguments in support of recommendations and decisions that centre on personal, social or global situations (OECD, 2007b). Interestingly, on the 2006 PISA test only 1.3% of the students fully achieved this level. In one example of a PISA sample item the students are required to analyse the nutrition and energy values of chocolate and reason if fats are the only energy source in chocolate or not, and make a decision regarding vitamin C sources (OECD, 2007a). (See full text in Figure 1.)

The PISA content dimension includes life systems, physical systems, earth and space systems, and technology systems. Knowledge in chemistry is not assessed separately. However, it is possible to use a similar framework to assess students’ chemical literacy by giving students a short adapted scientific article along with a few assignments (Dori & Sasson, 2008; Kaberman & Dori, 2009). A sophisticated view of reading assumes that students construct meaning from texts by exploration, inferring, and criticising what they read.

In chemical education, this means that students should provide reasons and evidence for their conclusions, and integrate them into their own cognitive worlds (Norris & Phillips, 2012). Doing this involves a sophisticated type of reading requiring metacognitive thinking, such as monitoring, controlling, and assessing (knowledge of regulation) while reading. In order to understand a text, students must ask themselves questions that monitor their understanding, such as how well they understand it or instruct themselves to do something if they did not understand the text (Zohar & Dori, 2012). It is therefore vital that chemistry teachers and
chemical educators understand and learn the hurdles that hamper successful and more sophisticated types of reading and act accordingly.

Read the following summary of an article in the newspaper the Daily Mail on March 30, 1998 and answer the questions which follow.

A newspaper article recounted the story of a 22-year-old student, named Jessica, who has a “chocolate diet.” She claims to remain healthy, and at a steady weight of 50kg, whilst eating 90 bars of chocolate a week and cutting out all other food, apart from one “proper meal” every five days. A nutrition expert commented: “I am surprised someone can live with a diet like this. Fats give her energy to live but she is not getting a balanced diet. There are some minerals and nutrients in chocolate, but she is not getting enough vitamins. She could encounter serious health problems in later life.” In a book with nutritional values the following data about chocolate are mentioned. Assume that all these data are applicable to the type of chocolate Jessica is eating all the time. Assume also that the bars of chocolate she eats have a weight of 100 grams each.

According to the table 100 g of chocolate contain 32 g of fat and give 2142 kJ of energy. The nutritionist said: “Fats give her the energy to live.” If someone eats 100 g of chocolate, does all the energy (2142 kJ) come from the 32 g of fat? Explain your answer using data from the table.

<table>
<thead>
<tr>
<th>Nutritional content of 100 g chocolate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proteins (g)</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>0.20</td>
</tr>
</tbody>
</table>

The nutrition experts said that Jessica “… is not getting nearly enough vitamins.” One of those vitamins missing in chocolate is vitamin C. Perhaps she could compensate for her shortage of vitamin C by including a food that contains a high percentage of vitamin C in her “proper meal every five days.”

Here is a list of types of food:

1. Fish
2. Fruit
3. Rice
4. Vegetables

Which two types of food from this list would you recommend to Jessica in order to give her a chance to compensate for her vitamin C shortage?

1 and 2
1 and 3
1 and 4

Figure 1. Sample item from the PISA study

Pedagogical recommendations for attainment of chemical literacy

- Provide a wide range of chemical ideas. Many introductory high-school courses focus on structure of matter almost exclusively. This results in students possessing a relatively narrow view of chemistry. We therefore suggest introducing a variety of ideas and concepts. For example, introducing the topic of energy changes and their implications in chemical reactions should be done without the calculation of enthalpy changes, which should be left to advanced levels. Also, the concept energy of activation should be introduced in order to
enrich students’ understanding of chemical reactions, and to allow them to explain facts such as why fossil fuels do not react with oxygen at room temperature, and why we need to strike the head of a match against a rough surface in order to light it. Another suggestion is that introductory courses should provide the students with a wide scientific vocabulary that would be relevant to their functioning as adults. For example, it is suggested that students should have an idea of what an acid, a protein, and polymers are. The concepts introduced have to meet the following criteria (at least one of them): it is common and useful in everybody’s daily life, and it has value in explaining phenomena.

– Decrease the domination of chemical language. This recommendation is made in order to minimise the preparatory character of a basic chemistry course, and to decrease the difficulties that many non-science-oriented students have regarding the use of chemical symbols. It is also suggested that students should be provided with symbols and representations, when necessary, and will be asked to use them effectively. This should prevent an overload of the short-term memory system, and allow students to practice other higher-order thinking skills. Verbal explanation should be considered to be more important than exercising symbols.

– Promote understanding the nature of science. This aspect is important because it contributes to general scientific literacy, to rational thinking and inquiry skills of the students. In many countries this aspect is absent in the formal syllabus, and it is the teachers choice to introduce it, model it, and discuss it. Aspects of the nature of science should be introduced through the whole sequence of learning, and not as a single or sporadic occasion. Reading articles, which demonstrate the scientific inquiry process and the laboratory work, are possible strategies for addressing this aspect.

– Increase the perception of relevance of chemistry studies. This is in-line with the ‘student-centred’ approach. The functioning of the students in future situations, and the ability to utilise knowledge are considered as essential characteristics of a literate person. Therefore, the focus should be on making clear the relevance and importance of chemical knowledge to daily life, and on developing learning skills rather than the current emphasis on knowing chemical facts. Contextual knowledge also has a role in increasing curiosity and motivation.

– Explicate knowledge organisation. An important aspect of conceptual chemical literacy is the development of some understanding of the major conceptual schemes of the discipline. Integrating and organising knowledge are required rather than perceiving chemical concepts as different and isolated pieces of knowledge. The ideas presented to the students should provide them with a wide and coherent view of what chemistry is all about. A major strategy that enables the development of conceptual schemes is to use all sorts of graphic organisers. Students should be given the opportunity and guidance to build diagrams, concept maps, flowcharts, and other knowledge organisers (see Chapter 7). Also, introducing all main dimensions of chemistry knowledge together,
namely, structure, energy, and dynamics is recommended. It is suggested that these strategies would enable students to develop a more realistic conceptual scheme of chemistry.

- **Focus on the development of higher-order thinking skills.** Many chemistry teachers tend to focus mainly on content knowledge and pay only limited attention to skills development. The development of general educational skills should be considered as a first priority goal for the chemistry education at the secondary level. The skills should address the needs of the general public, rather than the needs of those who continue with their science studies. High-school graduates are expected to be able to look for knowledge when needed, and to critically read scientific information, presented in different aspects of mass media publications.

- **Recognise two platforms of instruction.** Many teachers find themselves in the situation of teaching chemistry to a heterogeneous population. Some of the students do not intend to choose science (or chemistry) as a major, and take the course as part of a general education toward scientific literacy. Others do consider studying chemistry at the tertiary level, and expect to get an appropriate preparation. The chemistry course should address the needs of these two populations. We believe that students who are interested in a scientific career need to be as chemically literate as anyone else, at the very least. Therefore, addressing the variety of aspects of chemical literacy is needed also among students who constitute this group. However, it is important to maintain the interest and motivation among the ones who intend to study science in the future. It is suggested that two platforms of instruction should be constructed: The basic platform would introduce the main ideas in chemistry in a relevant context, and in a very general way, aiming at ‘chemical literacy’ of the general public. Apart from this platform, additional short units should provide a deeper and more detailed insight into the same chemical content. These units would allow the interested students to delve into specific and detailed scientific knowledge, without frustrating the other students around them. These units would be optional. For example, when teaching about the atom, the whole class can be involved in studying about the main discoveries that led to the current model of the atom, about protons, neutrons and electrons, and about how our understanding of the atom led to discoveries such as the ability to produce nuclear energy. At this point, only for those students who are interested in doing so, the teaching would include information that will deepen students’ understanding of nuclear reactions, or of orbitals and ionizations energies, electronic affinity, etc.

- **Use embedded assessment and a variety of assessment methods.** The assessment of the students should include both formative and summative evaluation and be continuous throughout the whole period of study. Teachers may assess their students traditionally via multiple choice and open-ended questions, but in addition the assessment should include, for example:
  - Portfolio of laboratory reports,
THE PRACTICE OF CHEMISTRY TEACHING

In the practical examples we will first discuss setting up of goals for chemistry teaching and introduce different proposals for structuring. After this, we will introduce different examples for assessments starting from assessing factual understanding and moving towards chemical literacy assessment.

Setting up objectives for chemistry teaching

Understanding the various justifications for teaching chemistry is a first step for setting up learning objectives or goals. However, setting learning goals is a delicate task that needs to take into account multiple aspects:

The students. Teachers need to consider many factors regarding their students before setting learning goals: age, students’ goals for taking the chemistry course – is it for general education or did they choose chemistry as a major – or, students’ prior knowledge in science in general and in chemistry in particular. Having a clear idea about the students’ expectations, motivation and capacities will allow teachers to set more realistic goals (see Chapter 3).

Content knowledge. The content knowledge may be specified by a national or regional syllabus, a specific textbook or by the teachers themselves. Teachers need to ask themselves the following questions regarding the content knowledge:

- What is the purpose for teaching this knowledge? Why is this idea/information important for my students?
- What is the depth and breadth of scientific detail in which this content will be presented? For example, we can teach the atomic structure of matter in various levels of depth: (a) All substances are made of small particles that are called atoms. This level allows presenting the concepts of molecules, states of matter and phase changes at the molecular level. In more detail, we can teach the idea that: (b) Atoms are made of a positive nucleus and negative electrons that are in constant motion around the nucleus. This latter idea will allow us to present the concepts of charged particles (ions), ionic lattice, reduction-oxidation, electrolysis, and precipitation reactions. We can even teach in more detail: (c) All atoms are made of a nucleus which is composed of positive particles (protons) and neutral particles (neutrons). Negatively charged particles (electrons) are around the nucleus, and have defined levels of energy. The latter detail allows us to present concepts such as atomic mass, isotopes, orbitals, and
probability of finding an electron, electron configuration, radioactivity, and nuclear reactions. By specifying the learning goals it would be easier to determine the level of scientific detail required in the syllabus for the class.

– Do I want to present all four levels of chemistry understanding regarding to a specific content idea (macro, submicro, symbolic, and process level; see Chapter 4 and below)?

Thinking skills and scientific practices. This aspect combines both students’ skills and the content. A leading question here is: What does one want his/her students to be able to do with the content one teaches? The answer here should refer both to thinking skills that one wants the students to develop (such as question posing, analysing, criticising), and what scientific practices one intends them to experience and develop (such as using or creating models, engaging in various aspects of inquiry, etc).

Higher order thinking skills

| Creating | Evaluating | Analysing | Applying | Understanding | Remembering |

Lower order thinking skills

![Bloom's revised taxonomy](image)

For setting goals regarding thinking skills we find that using a common taxonomy, such as the Bloom revised taxonomy (Bloom, 1956; Pohl, 2000) may be useful (Figure 2). Students can use the concepts, ideas and information presented in the chemistry course in various levels of thinking: they can simply memorise and remember, understand the meaning, apply to a different context (referred to as ‘transfer’), analyse a complex phenomenon, or investigate the relationships between concepts, evaluate the validity of an argument, the quality of experimental data, and the limitations of a specific model, etc. At the highest level, students create their own pattern, structures and generalisations.

In Table 1, we demonstrate how using this taxonomy is helpful in formulating various learning objectives in chemistry. The learning objectives are taken from a chemistry unit that is aimed at teaching the particulate structure of matter through engaging students in creating models to explain the phenomenon of smell. The unit name is: How do I smell things from a distance (Dalpe, Heitzman, Krajcik, Merritt, Rogat, & Shwartz, 2006).

In addition to Bloom’s taxonomy, in the last two decades, higher-order thinking skills have been described as complex skills with no simple algorithm for constructing a solution path (Resnick, 1987). These skills may include posing questions, inquiry, critical thinking, modelling, graphing, and transfer. Solving assignments that require higher order thinking skills are also referred to in the
literature as ill-structured problems that call for a variety of thinking patterns that are not well defined and have no definite single correct response (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004).

Another useful approach for setting learning goals is using the definition of chemical literacy presented in this chapter to formulate learning objectives in each of the domains. We will illustrate this approach by analysing a chapter from the programme: Salters Advanced Chemistry (Burton, Holman, Lazonby, Piling, & Waddington, 2000; see Chapter 1). This programme is a context-based chemistry course aimed at advanced level students in the UK. The chapter in Salters textbook that will be analysed here is called Engineering Proteins and deals with the structure and function of proteins (Table 2).

Assessing levels of understanding chemistry and interdisciplinarity

Based on the early suggestion of Johnstone (1991), chemistry educators and researchers, discuss the properties of substances and how they react on three levels of understanding (Gabel, 1998; Gilbert & Treagust, 2008; Johnstone, 2000; Treagust & Chittleborough, 2001):

– **Macroscopic nature of matter**: The sensory/visible phenomena which can be seen with the naked eye,

– **Particulate or submicroscopic nature of matter**: The submicroscopic level, dealing with atoms, molecules, and ions and their spatial structure, and

– **The symbolic representations of matter**: Chemical formulae, graphs and equations.

Dori and Hameiri (2003), Barak and Dori (2005), and Dori and Sasson (2008) suggested a fourth level – the process level, in which substances can be formed or decomposed, or react with other substances (see also Chapters 4 and 8).

In a study by Dori and Kaberman (2012), the researchers investigated whether students understood the process level by giving the students a case study about rotten apples and the patulin substance which may cause cancer. This case study involves food and health issues in addition to the chemical domain. First the students received the following narrative:

Are there brown, rotten, soft areas in your apple? If so, don’t eat it. The rotting in your apple is caused by a fungus that produces the carcinogenic toxin patulin in its tissues. This happens mainly in apples and pears after harvest, during storage. The patulin is an organic substance, whose molecular formula is C$_7$H$_6$O$_4$ and which appears in room temperature as white crystals.

Then, the students were asked to pose their own questions. Secondly, they were asked to respond to the following assignment:
2. OBJECTIVES AND ASSESSMENT

Table 1. Examples and key words to operate Bloom’s taxonomy for learning objectives

<table>
<thead>
<tr>
<th>Thinking skill</th>
<th>Example</th>
<th>Key words</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remembering: Recall previously learned information.</td>
<td>Students identify materials in three states of matter, using scientific terminology (solid, liquid, gas) and describe typical changes of states that occur when substances are heated or cooled.</td>
<td>defines, describes, identifies, knows, labels, lists, matches, names, outlines, recalls, recognises, reproduces, selects, states</td>
</tr>
<tr>
<td>Understanding: Comprehending the meaning, translation, interpolation, and interpretation of instructions and problems. State a problem in one’s own words.</td>
<td>Students characterize things as matter (or not matter) based on whether they have mass and volume. They provide examples of materials changing states.</td>
<td>comprehends, converts, defends, distinguishes, estimates, explains, extends, generalises, gives an example, infers, interprets, paraphrases, predicts, rewrites, summarises, translates</td>
</tr>
<tr>
<td>Applying: Use a concept in a new situation or unprompted use of an abstraction. Applies what was learned in the classroom into novel situations in the work place.</td>
<td>Students apply their models of matter to explain why indicator paper changes colour when put above a liquid (but not touching it), and how smell travels.</td>
<td>applies, changes, computes, constructs, demonstrates, discovers, manipulates, modifies, operates, predicts, prepares, produces, relates, shows, solves, uses</td>
</tr>
<tr>
<td>Analysing: Separates material or concepts into component parts so that its organizational structure may be understood. Distinguishes between facts and inferences.</td>
<td>Students analyse the structures of different compounds to explain that different smells are caused by different arrangements of atoms in a molecule. They analyse the relationship between temperature and volume of gases.</td>
<td>analyses, breaks down, compares, contrasts, diagrams, deconstructs, differentiates, discriminates, distinguishes, identifies, illustrates, infers, outlines, relates, selects, separates</td>
</tr>
<tr>
<td>Evaluating: Make judgments about the value of ideas or materials.</td>
<td>Students evaluate the value of a scientific model and its limitations. They compare two graphs representing the same experiment conducted at two different temperatures.</td>
<td>assesses, appraises, compares, concludes, contrasts, criticises, critiques, defends, describes, discriminates, evaluates, explains, interprets, justifies, relates, summarises, supports</td>
</tr>
<tr>
<td>Creating: Builds a structure or pattern from diverse elements. Put parts together to form a whole, with emphasis on creating a new meaning or structure.</td>
<td>Students construct models to explain and account for all of the following phenomena: subtraction, addition, compression and expansion of gas in a closed container.</td>
<td>categorises, combines, compiles, composes, creates, devises, designs, explains, generates, modifies, organises, plans, rearranges, reconstructs, relates, reorganises, revises, rewrites, summarises, tells, writes</td>
</tr>
</tbody>
</table>
Table 2. Setting up objectives for chemistry teaching – the chemical literacy approach

<table>
<thead>
<tr>
<th>Content in the chapter</th>
<th>Domain in the chemical literacy definition</th>
<th>Learning goal – idea to be learned</th>
</tr>
</thead>
<tbody>
<tr>
<td>A story about an 11 years old boy who has diabetes and needs to inject insulin</td>
<td>Chemistry in context</td>
<td>Demonstrate the importance of chemical knowledge in finding treatments for medical problems. To demonstrate the applicative nature of chemical knowledge.</td>
</tr>
<tr>
<td></td>
<td>Affective aspects</td>
<td>Create motivation and interest for further learning</td>
</tr>
<tr>
<td>Various types and functions of protein in the human body</td>
<td>Chemical ideas</td>
<td>Chemistry explains protein’s functions in living systems in terms of chemical structures and the chemical processes</td>
</tr>
<tr>
<td>Graphs of insulin concentration in blood by time after eating a meal in a healthy and</td>
<td>Chemical ideas</td>
<td>Chemistry investigates the dynamics of processes and reactions</td>
</tr>
<tr>
<td>a diabetic person (with and without injecting insulin) including an explanation about</td>
<td>Higher-order thinking skills</td>
<td>Graphing skills which consists of analysing and comparing graphs of kinetics</td>
</tr>
<tr>
<td>the rate of forming monomers from hexamers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein building: Amino acids, condensation of amino acids, peptide link, primary structure, D.L. optical isomers, primary structure of human insulin</td>
<td>Chemical ideas</td>
<td>Chemistry explains macroscopic phenomena and structure of matter in terms of the microscopic/submicroscopic, symbolic, and process levels.</td>
</tr>
<tr>
<td>How cells make protein: DNA, RNA, tRNA, Ribosome, the codons, gene, genome</td>
<td>Chemical ideas</td>
<td>It explains protein synthesis in living cells in terms of chemical structures and processes</td>
</tr>
<tr>
<td>Genetic engineering</td>
<td>Chemistry in context</td>
<td>To demonstrate the applicative nature of chemical knowledge</td>
</tr>
<tr>
<td>Proteins in 3D – chemical interactions that dominate chain folding, primary, secondary,</td>
<td>Chemical ideas</td>
<td>Chemistry explains macroscopic phenomena and structure of matter in terms of the microscopic, symbolic, and process levels.</td>
</tr>
<tr>
<td>tertiary and quaternary structures of proteins in general and insulin in particular</td>
<td>Higher-order thinking skills</td>
<td>Chemistry explains proteins function in living systems in terms of chemical structures. Using multiple models and symbols: Chemists use various models, each of them illustrating a different aspect of the discussed phenomenon</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chemists use a specific language</td>
</tr>
<tr>
<td>Enzymes</td>
<td>Chemical ideas</td>
<td>Chemistry tries to explain macroscopic phenomena and structure of matter in terms of the submicroscopic, symbolic, and process levels.</td>
</tr>
<tr>
<td></td>
<td>Chemistry in context</td>
<td>Chemistry investigates the dynamics of processes and reactions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Demonstrate the applicative aspect of chemical knowledge</td>
</tr>
</tbody>
</table>
NaI is a white solid substance, whose molar mass is 150 g/mol with melting temperature of 662°C, while the molar mass of patulin is 154 g/mol, with melting temperature of 110°C. Describe the melting processes of NaI and patulin. Explain the difference between these two processes.

In the process of a posing questions assignment, the students are required to compose complex questions that include at least two scientific domains, more than one chemistry understanding level and present a higher-order thinking skill. In the assignment that dealt with NaI and patulin, the students are required to integrate their understanding of structural formula and ionic formula (the symbolic level) and transfer it to the melting processes (the process level). They have to express it via textual and symbolic explanations of the processes of both substances. In order to explain the process level, students also need to express their understanding in the submicroscopic level (bonding, etc.).

Students can be advised to use a metacognitive tool that includes criteria to monitor their responses (Herscovitz, Kaberman, Saar, & Dori, 2012). An example of the instructions included in the metacognitive tool is as follows: Reflecting on your thinking, when you responded to the questions did you include (a) at least two chemistry understanding levels, and (b) at least two scientific domains?

Difficulties in learning chemistry are mainly attributed to its abstract, unobservable submicroscopic nature and to the need for swift transfer across the various levels of chemistry understanding (Johnstone, 2000; Gabel, Briner, & Haines, 1992; Coll & Treagust, 2003). Several researchers (Gabel & Sherwood, 1980; Garnett, Tobin, & Swingler, 1985; Harrison & Treagust, 2000) suggested the use of concrete models to help students visualise the particulate nature of matter. With the improvement of computer graphics, CMM (Computerised Molecular Modelling) has become a sustainable tool for engaging students in constructing models and in practicing inquiry activities which may promote students’ ability of mentally traversing among the four levels of chemistry understanding (Chiu & Wu, 2009; Barnea & Dori, 2000) (see Chapter 8).

Use alternative assessments in chemistry lessons

There is a range of ways for assessing students’ learning outcomes of the formal chemistry curricula though most teachers rely on standard tests and quizzes. Chemistry teachers’ pedagogy can be made more effective by using diagnostic formative assessment methods (Bell & Cowie, 2001). Indeed, current assessment procedures can distort and narrow instruction, thereby misrepresenting the nature of the subject, and maintaining inequities in access to education and are claimed to not provide valid measures of what students know and to provide no opportunity for students and teachers to be involved in discussions about the work being assessed. Alternative assessment methods include portfolios (Naylor, Keogh, & Goldworthy, 2004), case studies or adapted scientific articles followed by thinking skills assignments (Dori & Kaberman, 2012; Kaberman & Dori, 2009), diagnostic
tests, and the Predict-Observe-Explain (POE) instructional strategy. The latter two approaches are described below.

Diagnostic tests. One approach to alternative assessment is using two-tier multiple-choice test items specifically for the purpose of identifying students’ alternative conceptions in limited and clearly defined content areas (Treagust, 1988). These paper and pencil tests are convenient to administer and not time consuming to mark. The first tier of each multiple-choice item consists of a content question having usually two to four choices. The second tier of each item contains a set of usually four possible reasons for the answer given to the first part. The reasons consist of the designated correct answer, together with identified students’ conceptions and/or misconceptions. Students’ answers to each item are considered to be correct when both the correct choice and correct reason are given. Supporters of alternative approaches to assessment recommend assessment items that “require an explanation or defence of the answer, given the methods used” (Wiggins & McTighe, 1998, p. 14) – precisely the information required in the second tier of two-tier test items.

Tan and Treagust (1999) were interested in 14-16 year olds studying chemical bonding with the first tier response made relatively easy with a true-false choice while the second tier still probed deeply an understanding behind the first tier response. An example is shown in Figure 3.

Sodium chloride, NaCl, exists as a molecule.

<table>
<thead>
<tr>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>A The sodium atom shares a pair of electrons with the chlorine atom to form a simple molecule.</td>
</tr>
<tr>
<td>B After donating its valence electron to the chlorine atom, the sodium ion forms a molecule with the chloride ion.</td>
</tr>
<tr>
<td>C Sodium chloride exists as a lattice consisting of sodium ions and chloride ions.</td>
</tr>
<tr>
<td>D Sodium chloride exists as a lattice consisting of covalently bonded sodium and chlorine atoms.</td>
</tr>
</tbody>
</table>

Figure 3. Example of a two-tier true-false test item

Following a specially designed teaching programme using multiple representations in chemistry, Chandrasegaran, Treagust and Mocerino (2011) administered the Representational Systems and Chemical Reactions Diagnostic Instrument two-tier test items to identify grade 9 students’ representational competence in explaining chemical reactions using chemical symbols, formulae and equations (symbolic level) as well as atoms, molecules and ions (submicroscopic level) based on the changes observed during chemical reactions (macroscopic level) (see Chapter 4).
As an example, in Figure 4 when iron powder reacts with dilute hydrochloric acid, a green solution of aqueous iron(II) chloride is produced (explanation at the macroscopic level). The colour change of the solution from colourless to green may be attributed to the presence of Fe$^{2+}$ ions in solution (explanation at the submicroscopic level). Some students (15%), however, suggested that atoms of iron and chlorine had turned green as a result of the chemical reaction, indicating possible confusion between the colour change at the macroscopic level with changes to the elements iron and chlorine at the submicroscopic level.

Dilute hydrochloric acid is added to some grey iron powder. Vigorous effervescence occurs as hydrogen gas is produced. The iron powder disappears producing a light green solution.

Why did the solution change to a light green colour?
A Iron is coloured light green in solution.
B Iron(II) chloride was produced in aqueous solution.
C The iron combined with chlorine to form iron(II) chloride.

The reason for my answer is:
1 Fe$^{2+}$ ions in aqueous solutions of their salts produce light green solutions.
2 When both iron and chlorine atoms combine they become green in colour.
3 Atoms of the iron powder dissolve in hydrochloric acid and become green in colour.

**Figure 4. Example of a two-tier multiple choice item**

*Predict-Observe-Explain (POE) instructional strategy.* Following a teacher in-service programme on the use of the Predict-Observe-Explain (POE) instructional strategy to enhance grade 11 South African students’ understanding of redox reaction concepts, its efficacy was evaluated by Mthembu (2006). Eight hands-on POE activities involving redox reactions were conducted over a four-week period by teachers who had participated in the programme. Instruction was evaluated using multiple methods, including laboratory observations, interviews with students, questionnaires to assess students’ attitudes concerning the use of POEs, and a 25-item pre- and a post-test on redox reactions. An example of the instructions for carrying out one of these POE activities is provided in Figure 5 while the expected changes that occur are illustrated in a diagram and in text.
Immerse a zinc strip in aqueous copper (II) sulfate

Instructions to students:
1. You will investigate the redox reaction that occurs when a zinc strip is dipped in beaker containing some aqueous copper (II) sulfate.
2. Collect the materials and solution required for this activity.
3. Predict whether a chemical reaction will take place. Write a brief explanation or reason for your prediction.
4. Share your prediction with members of your group and come to an agreement of what you would expect to happen.
5. Perform the experiment. What changes can you observe? Record all changes that occur. Were your observations similar to your earlier predictions?
6. Write down your explanations for all changes that you observed in terms of the redox reaction that had occurred. Compare your observations with your prediction. Are these in agreement? If not, discuss with members of your group to reconcile any differences.

Zinc displaces copper from aqueous solution as zinc is more reactive than copper. The blue copper(II) sulfate solution fades and becomes colourless due to the formation of aqueous zinc sulfate, and a reddish-brown deposit of copper is produced. Zinc reduces Cu²⁺ ions to copper and is itself oxidised to Zn²⁺ ions.

\[ \text{Zn}(s) + \text{Cu}^{2+}(aq) \rightarrow \text{Zn}^{2+}(aq) + \text{Cu}(s) \]

Figure 5. Example for the Predict-Observe-Explain (POE) strategy

Assessing chemical literacy by understanding and extracting meanings from adapted scientific articles

One way to assess students’ chemical literacy is to confront them with authentic media. Based on Wandersee’s Ways students read texts questionnaire (1988), and Herscovitz, Kaberman, Saar, and Dori’s (2012) adapted questionnaire one can assess whether a student is able to cope with chemistry related information in life.

A task to be given might be:
Read the following article and then answer the questions, assuming you are to be tested for understanding the article:
1) What method do you usually use for reading and understanding the article? Explain your favourite method.
2) While reading a new article, do you ask yourself questions? If so, give an example for one such question.
2. OBJECTIVES AND ASSESSMENT

4) (a) Are you interested in having guiding instructions for meaningful reading of scientific articles? Please explain why [in case guiding instructions were not given], and (b) did the guiding instructions for meaningful reading of scientific articles you used assisted you to better understand the articles? Explain how [in case guiding instructions were given].

When conducting content analysis of students’ responses to the first question, one can identify three strategies for reading and understanding adapted articles:

– **Skimming**: A low strategy, in which students search answers to questions by repeated rereading and/or reading aloud,
– **Looking for meaning**: An intermediate strategy, in which students looking at the title, using tools such as outlines, diagrams, highlighting a basic term or a key word, and
– **Contextual understanding**: A high strategy, in which students connect the new knowledge to prior knowledge (Herscovitz et al., 2012).

<table>
<thead>
<tr>
<th>In making the lip gloss and lipstick, oil and waxes are mixed together. The colouring substance and flavouring are then added.</th>
<th>Figure 6. Example of an embedded assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>The lipstick made from this recipe is hard and not easy to use. How would you change the proportion of ingredients to make a softer lipstick?</td>
<td></td>
</tr>
<tr>
<td>Oils and waxes are substances that will mix well together. Oils cannot be mixed with water, and waxes are not soluble in water.</td>
<td></td>
</tr>
<tr>
<td>Which one of the following is most likely to happen if a lot of water is splashed into the lipstick mixture while it is being heated?</td>
<td></td>
</tr>
<tr>
<td>A. A creamier and softer mixture is produced.</td>
<td></td>
</tr>
<tr>
<td>B. The mixture becomes firmer.</td>
<td></td>
</tr>
<tr>
<td>C. The mixture is hardly changed at all.</td>
<td></td>
</tr>
<tr>
<td>D. Fatty lumps of the mixture float on the water.</td>
<td></td>
</tr>
<tr>
<td>When substances called emulsifiers are added, they allow oils and waxes to mix well with water.</td>
<td></td>
</tr>
<tr>
<td>Why does soap and water remove lipstick?</td>
<td></td>
</tr>
<tr>
<td>A. Water contains an emulsifier that allows the soap and lipstick to mix.</td>
<td></td>
</tr>
<tr>
<td>B. The soap acts as an emulsifier and allows the water and lipstick to mix.</td>
<td></td>
</tr>
<tr>
<td>C. Emulsifiers in the lipstick allow the soap and water to mix.</td>
<td></td>
</tr>
<tr>
<td>D. The soap and lipstick combine to form an emulsifier that mixes with the water.</td>
<td></td>
</tr>
</tbody>
</table>

**In making the lip gloss and lipstick, oil and waxes are mixed together. The colouring substance and flavouring are then added.**

**The lipstick made from this recipe is hard and not easy to use. How would you change the proportion of ingredients to make a softer lipstick?**

Oils and waxes are substances that will mix well together. Oils cannot be mixed with water, and waxes are not soluble in water.

**Which one of the following is most likely to happen if a lot of water is splashed into the lipstick mixture while it is being heated?**

A. A creamier and softer mixture is produced.
B. The mixture becomes firmer.
C. The mixture is hardly changed at all.
D. Fatty lumps of the mixture float on the water.

When substances called emulsifiers are added, they allow oils and waxes to mix well with water. **Why does soap and water remove lipstick?**

A. Water contains an emulsifier that allows the soap and lipstick to mix.
B. The soap acts as an emulsifier and allows the water and lipstick to mix.
C. Emulsifiers in the lipstick allow the soap and water to mix.
D. The soap and lipstick combine to form an emulsifier that mixes with the water.
Embedded assessment

The Programme for International Student Assessment (PISA) by the OECD (see above) tries to connect both – assessing conceptual understanding and scientific literacy. PISA assessments are always based on a short text giving specific information for the task. Starting from the text different tasks are given assessing the different domains of knowledge and skills to be assessed.

One example is introducing the tasks by a conversation with a farmer that discusses three uses of corn as a source of energy: as food, as a burning material to provide heat and light and as possible fuel. In the items following the text, the students are required to understand the similarities and differences regarding the chemical nature of each use, and relate the use of corn as fuels to possible effect both on plants photosynthesis rate and of the greenhouse effect.

In the example in Figure 6, the ingredients of lipstick and lip-gloss are provided. The underlying chemical ideas are that a change in the chemical composition leads to a change in properties, and that understanding the structure and bonding of matter allows us to use specific materials to specific uses (such as the use of emulsifiers to mix oils and water). Understanding structure, bonding of water, oils, waxes and emulsifiers are also required. These ideas can be studied in the chemistry class in various levels – from a very general introduction to deep and meaningful understanding.

SUMMARY: KEY SENTENCES

- The chemistry curriculum at the high-school level should address the current goal of attainment of scientific literacy for all students.
- Chemical literate students should have the ability to see the relevance and usability of chemistry in many related contexts.
- Chemistry understanding levels should include the macroscopic, sub-microscopic, symbolic, and process levels.
- It is important to maintain the interest and motivation of all students who study chemistry. However, we should not forget the ones who intend to study science in the future.
- A chemically literate student, who learned to develop his/her higher-order thinking skills, should be able to read an adapted scientific paper, raise a complex question, and look for information to make judicious decisions.
- Focus should be on embedded assessment that will fit the innovative curriculum and the chemical literacy approach.
2. OBJECTIVES AND ASSESSMENT

ASK YOURSELF

1. Explain and give an example: What is scientific literacy?
2. List advantages and disadvantages of teaching in context or socio-scientific issues-based settings vs. structure of the discipline curricula.
3. Choose five important concepts from this chapter and draw a scheme or diagram how to use them in your classroom.
4. Design three types of assignments for high school students who major in chemistry:
   - A traditional quiz – for example 10 multiple choice questions or true false questions,
   - A case study or adapted scientific task – for example a 500-word-narrative based on a primary scientific paper followed by a task of posing complex questions, and
   - A thinking skill task – such as draw a graph based on the data given in a table describing the types of molecules detected in air monitored for its quality.
5. Reflect on your thinking, while composing a rubric for grading your students’ responses to the assignments you designed in Task 4. Make sure to include in your rubric criteria for (a) correct chemical knowledge, (b) at least two chemistry understanding levels, (c) at least two scientific domains, and (d) lower- vs. higher-order thinking responses.

HINTS FOR FURTHER READING


SHWARTZ, DORI & TREAGUST


RESOURCES FROM THE INTERNET

PISA: [www.pisa.oecd.org/](http://www.pisa.oecd.org/). The *Programme for International Student Assessment* aims to evaluate education systems worldwide by testing the skills and knowledge of 15-year-old students in participating countries/economies. Since the year 2000 over 70 countries and economies have participated in PISA. Their reports, test items and other publications are available in this site.


NSTA: [www.nsta.org/](http://www.nsta.org/). This website contains information about resources for teaching science education at all levels. In addition the website contains current science news, availability of conferences and on-line workshops. Membership of NSTA is needed to view all items though some are available free.

REFERENCES


2. OBJECTIVES AND ASSESSMENT


2. OBJECTIVES AND ASSESSMENT


