TEACHING CHEMISTRY – A STUDYBOOK

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

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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.

- *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

INGO EILKS, FRANZ RAUCH, BERND RALLE & AVI HOFSTEIN

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

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

THEORETICAL BASIS

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

Preparing future scientists vs. science education for all

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The idea of the curriculum emphases

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

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

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

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

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

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

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

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

Basic orientations of the chemistry curriculum

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

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

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

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

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

"Knowledge Development in Chemistry"-oriented science curricula

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

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

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

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

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

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

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

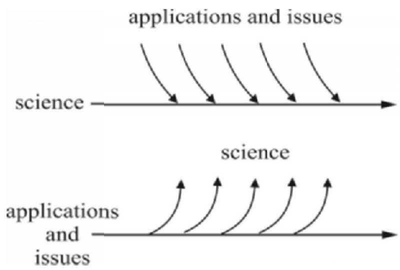

Figure 1. Traditional curricula driven by the structure of the discipline vs. curricula driven by applications and issues (Holman, 1987)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Education for Sustainable Development (ESD) and the chemistry curriculum

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

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

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

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

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

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

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

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

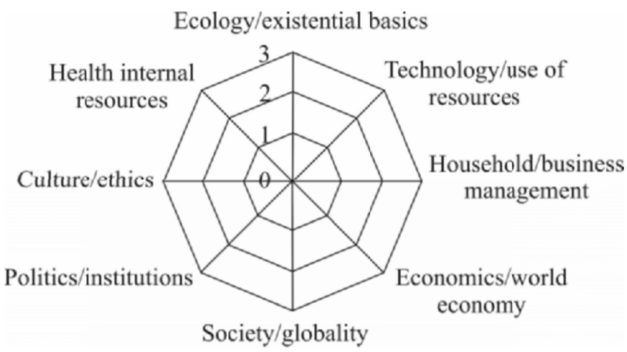

Figure 2. Spider of topics for reflecting ESD teaching (Kyburz-Graber et al., 2010)

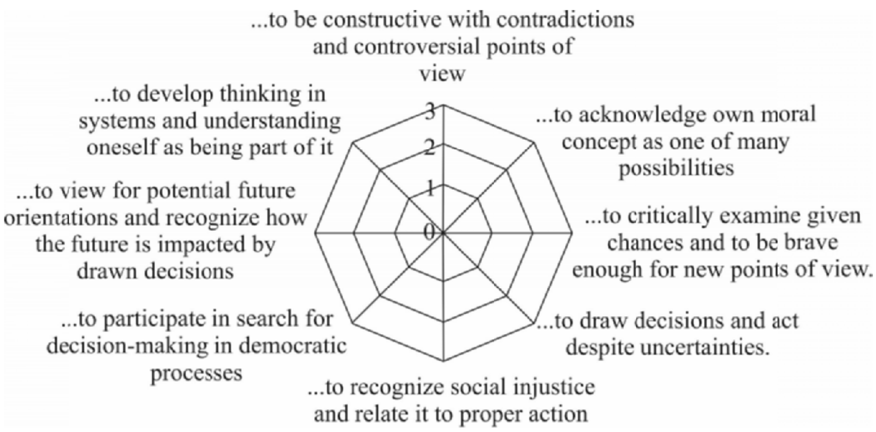

Figure 3. Spider of principles for reflecting ESD teaching (Kyburz-Graber et al., 2010)

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

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

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

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

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

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

THE PRACTICE OF CHEMISTRY TEACHING

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

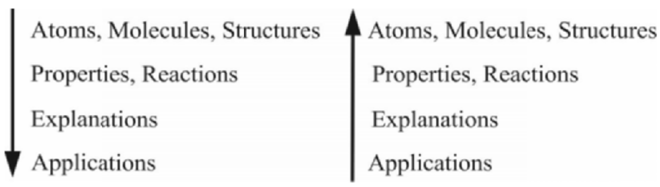

Figure 4. A change in directions (Reid, 2000)

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

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

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

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

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

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

Context-based chemistry curricula

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

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

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

Table 5. Contexts used in ChemCom

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

Within ChemCom every unit followed the same pattern:

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

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

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

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

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

Table 6. Sketch from a Salters curriculum unit

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

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

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

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

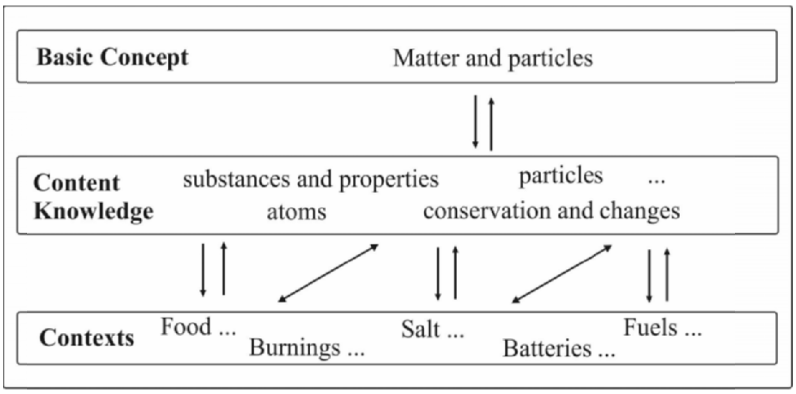

Figure 5. Building up basic concepts from different contexts

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

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

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

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

Socio-scientific issues based chemistry teaching

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

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

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

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

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

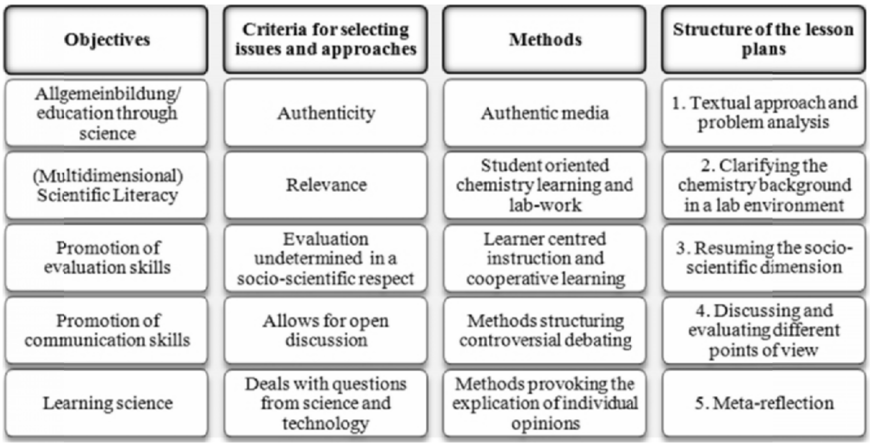

Figure 6. The socio-critical and problem-oriented approach to chemistry teaching

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

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

Education for Sustainable Development (ESD) and chemistry teaching

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

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

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

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

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

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

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

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

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

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

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

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

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

SUMMARY: KEY SENTENCES

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

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

ASK YOURSELF

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

HINTS FOR FURTHER READING

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

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

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

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

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

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

RESOURCES FROM THE INTERNET

D. Warren: The Nature of Science at www.rsc.org/images/Nature%20of%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. A current curriculum development project from the UK is presented. Materials are offered for context-based and scientific literacy oriented science education.

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

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

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

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YAEL SHWARTZ, YEHUDIT JUDY DORI & DAVID F. TREAGUST

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,

I. Eilks and A. Hofstein (eds.), Teaching Chemistry – A Studybook, 37–65.

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 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.

Nutritional content of 100 g chocolate

Proteins (g)	Fats (g)	Carbohy-drates (g)	Minerals		Vitamins			Total energy (kJ)
			Calcium (mg)	Iron (mg)	A	B (mg)	C	
5	32	51	50	4	-	0.20	-	2142

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,

– Case-based assignments that include a narrative from everyday phenomena and processes,
– Oral presentations by individuals or pair of students, and students' reflections.

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 charges 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).

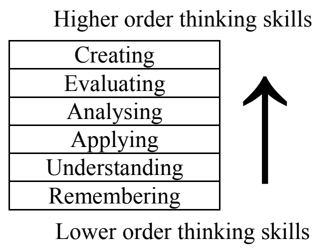


Figure 2. Bloom's revised taxonomy

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 $C_7H_6O_4$ 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:

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

Thinking skill	***Example***	***Key words***
Remembering: Recall previously learned information.	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.	defines, describes, identifies, knows, labels, lists, matches, names, outlines, recalls, recognises, reproduces, selects, states
Understanding: Comprehending the meaning, translation, interpolation, and interpretation of instructions and problems. State a problem in one's own words.	Students characterize things as matter (or not matter) based on whether they have mass and volume. They provide examples of materials changing states.	comprehends, converts, defends, distinguishes, estimates, explains, extends, generalises, gives an example, infers, interprets, paraphrases, predicts, rewrites, summarises, translates
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.	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.	applies, changes, computes, constructs, demonstrates, discovers, manipulates, modifies, operates, predicts, prepares, produces, relates, shows, solves, uses
Analysing: Separates material or concepts into component parts so that its organizational structure may be understood. Distinguishes between facts and inferences.	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.	analyses, breaks down, compares, contrasts, diagrams, deconstructs, differentiates, discriminates, distinguishes, identifies, illustrates, infers, outlines, relates, selects, separates
Evaluating: Make judgments about the value of ideas or materials.	Students evaluate the value of a scientific model and its limitations. They compare two graphs representing the same experiment conducted at two different temperatures.	assesses, appraises, compares, concludes, contrasts, criticises, critiques, defends, describes, discriminates, evaluates, explains, interprets, justifies, relates, summarises, supports
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.	Students construct models to explain and account for all of the following phenomena: subtraction, addition, compression and expansion of gas in a closed container.	categorises, combines, compiles, composes, creates, devises, designs, explains, generates, modifies, organises, plans, rearranges, reconstructs, relates, reorganises, revises, rewrites, summarises, tells, writes

Table 2. Setting up objectives for chemistry teaching – the chemical literacy approach

Content in the chapter	***Domain in the chemical literacy definition***	***Learning goal – idea to be learned***
A story about an 11 years old boy who has diabetes and needs to inject insulin	Chemistry in context Affective aspects	Demonstrate the importance of chemical knowledge in finding treatments for medical problems. To demonstrate the applicative nature of chemical knowledge Create motivation and interest for further learning
Various types and functions of protein in the human body	Chemical ideas	Chemistry explains protein's functions in living systems in terms of chemical structures and the chemical processes
Graphs of insulin concentration in blood by time after eating a meal in a healthy and a diabetic person (with and without injecting insulin) including an explanation about the rate of forming monomers from hexamers	Chemical ideas Higher-order thinking skills	Chemistry investigates the dynamics of processes and reactions Graphing skills which consists of analysing and comparing graphs of kinetics
Protein building: Amino acids, condensation of amino acids, peptide link, primary structure, D,L optical isomers, primary structure of human insulin	Chemical ideas	Chemistry explains macroscopic phenomena and structure of matter in terms of the microscopic/ submicro-scopic, symbolic, and process levels.
How cells make protein: DNA, RNA, m-RNA, tRNA, Ribosome, the codons, gene, genome	Chemical ideas	Chemistry explains macroscopic phenomena and structure of matter in terms of the microscopic/submicro-scopic, symbolic, and process levels It explains proteins synthesis in living cells in terms of chemical structures and processes
Genetic engineering	Chemistry in context	To demonstrate the applicative nature of chemical knowledge
Proteins in 3D – chemical interactions that dominate chain folding, primary, secondary, tertiary and quaternary structures of proteins in general and insulin in particular	Chemical ideas Higher-order thinking skills	Chemistry explains macroscopic phenomena and structure of matter in terms of the microscopic, symbolic, and process levels 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 Chemists use a specific language
Enzymes	Chemical ideas Chemistry in context	Chemistry tries to explain macroscopic phenomena and structure of matter in terms of the submicroscopic, symbolic, and process levels. Chemistry investigates the dynamics of processes and reactions Demonstrate the applicative aspect of chemical knowledge

> NaI is a white solid substance, whose molar mass is 150 g/mol with melting temperature of 662^{o}C, while the molar mass of patulin is 154 g/mol, with melting temperature of 110^{o}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.

I True II False.

Reason:

A The sodium atom shares a pair of electrons with the chlorine atom to form a simple molecule.
B After donating its valence electron to the chlorine atom, the sodium ion forms a molecule with the chloride ion.
C Sodium chloride exists as a lattice consisting of sodium ions and chloride ions.
D Sodium chloride exists as a lattice consisting of covalently bonded sodium and chlorine atoms.

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.

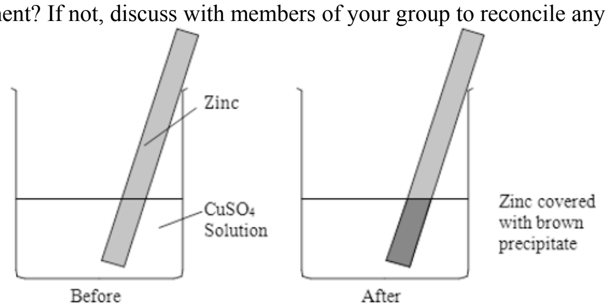
Figure 4. Example of a two-tier multiple choice item

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.

Immersing 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 Cu^{2+} ions to copper and is itself oxidised to Zn^{2+} ions.

$$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$$

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.*
> *3) While reading a new article, do you ask yourself questions? If so, give an example for one such question.*

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).

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.
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.

Figure 6. Example of an embedded assessment

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.

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, Y., Ben-Zvi, R., & Hofstein, A. (2006). Chemical literacy: What does it mean to scientists and school teachers? *Journal of Chemical Education*, *83*, 1557-1561. This paper extends the theoretical background of scientific literacy and set the stage for context-based teaching in chemistry.

Gilbert, J. K., & Treagust, D. F. (eds.) (2009). *Multiple representations in chemical education.* Dordrecht: Springer. This book provides many examples and discusses issues of chemistry teaching that involves chemical representations.

Zohar, A., & Dori, Y. J. (eds.) (2012). *Metacognition in science education: Trends in current research*. Dordrecht: Springer. Expanding on the theoretical foundations of metacognition, the book presents studies on how various forms of metacognitive instruction enhance understanding and thinking in science classrooms in general and chemistry education in particular.

Treagust, D. F., & Chiu, M.-H. (eds.) (2011). Special Issue: Diagnostic assessment in chemistry. *Chemistry Education Research and Practice, 12*, 119-120. This special issue has wealth of ideas about incorporating diagnostic assessment in chemistry teaching.

Naylor, S., Keogh, S., & Goldworthy, A. (2004). *Active assessment: Thinking, learning and assessment in science*. Sandbach: Millgate House. The book offers tools and practical examples for alternative assessment in science education.

RESOURCES FROM THE INTERNET

PISA: 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.

Strategies for science teaching and assessment: *sydney.edu.au/science/uniserve_science/school/support/strategy.html*. This is a large resource of strategies for science teaching and assessment.

NSTA: *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.

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CLAUS BOLTE, SABINE STRELLER & AVI HOFSTEIN

3. HOW TO MOTIVATE STUDENTS AND RAISE THEIR INTEREST IN CHEMISTRY EDUCATION

This chapter discusses the concepts of motivation and interest, and provides insight into the basic theories underlying these concepts. These theories explain why it is important for chemistry teachers to deal with these theories and what one can expect of students when they are motivated to learn and interested in learning. The chapter will also provide insights into what research revealed to be motivating and interesting to the students. In different classes the motivational preconditions are different and not every class or student, respectively, can be motivated in the same way. In the practice part of the chapter ideas are presented, which relate to the question of how motivating chemistry teaching can be planned and operated. Finally, a method of how to assess and reflect motivation in chemistry classes will be discussed.

THEORETICAL BASIS

Motivation, although not indispensable for limited and short-term learning, is absolutely necessary for sustained-type learning involved in mastering a given subject-matter discipline
(David P. Ausubel, Joseph D. Novak, & Helen Hanesian, 1978, p. 397)

What do the terms 'motivation' and 'interest' mean?

Other than a few important exceptions (for example, breathing, blinking or other things which we do instinctively or by reflex), how we think and take action is governed by our mind. No matter what we do, there is typically a motive or rationale for the action. This is true even if the action is to 'do nothing.'

One might ask the question, "what does it mean to 'do nothing'?" Let us give an example. Envisage the following: You are a chemistry teacher and you have asked your students to work on a task. As you observe your students you notice discrepancies in how they are working, some work in what appears to be, a highly organised fashion, fully focused on the task at hand. However, others appear

I. Eilks and A. Hofstein (eds.), Teaching Chemistry – A Studybook, 67–95.

disengaged, and seem to be 'doing nothing.' While it is possible that these students are notionally concerned with the task, it is often difficult to tell. At times, students may act out and interrupt the lesson. Regardless of how these students behave, the clear issue is that they are not motivated or engaged with the lesson. The individual interests and motivations of the students are obviously quite different in nature. While all students can be motivated, not all of them are motivated to work on any given task.

Motivation. Actions are connected with motivation, for example if students are asked to solve a problem in chemistry or not to disturb a lesson; their actions are stimulated by something, we tend to think of this as the motivation for their actions. Motivation is the driving force by which humans achieve their goals (Heckhausen, 1991; Lee & Brophy, 1996). It is not a characteristic one is born with nor is it inherent in the genes. Bandura (1986) clearly outlined that motivation is based on individual experiences or learning activities and that motivation is situational and context-related. Motivation can be discerned through the expressions of the individual but also through their related choice of activities, engagement, or performance (Pintrich & Schunk, 1996; Pintrich & Zuscho, 2003; Schraw, Flowerday, & Lehmann, 2001). Motivation is a psychological construct, clearly to be differentiated from other constructs such as *interest* or *attitudes;* although there are strong relations and partial overlaps (Koballa & Glynn, 2007).

Within the concept of "motivation" you can distinguish intrinsic from extrinsic motivation (Heckhausen, 1991; Koballa & Glynn, 2007). Psychological processes are activated by internal and external impulses. Therefore we need to differentiate between intrinsic and extrinsic motivation. Unfortunately, during the daily (teaching) routine it is not always easy to differentiate between intrinsic and extrinsic motivation. Let us return to our example: Are the students who try to solve the problem motivated exclusively extrinsically because you as teacher have given them the task (extrinsic impulse)? Is the motivation of the students who are not working on the problem intrinsically because, contrary to your request, they are dealing with other issues? Without further knowledge about the reasons or motives behind the students' behaviour both questions cannot be clearly answered with a simple yes or no. The answer strongly depends on the reason for working on the problem (what is the motive for this behaviour?) and the reason for being engaged with other tasks/issues.

One potential motivation for students may be to get a high grade. Other students may actively contribute to the lesson in order to win praise from the teacher. The motivation of both students would then be extrinsic, since they do not act by choice and due to their own interest but rather in a non-self-determined manner. Let us assume that a student is inquisitive and eager to work on problems and it even affords joy and satisfaction to him or her to work on challenging tasks either solely or together with others. In this case the student is intrinsically motivated (even though he has been given the task by his teacher). The conclusion in this case is that this student is self-determined (Ryan & Deci, 2000; Koballa & Glynn, 2007).

In order to determine whether behaviour is intrinsically or extrinsically motivated one has to consider two factors: The interaction of internal and external reasons and the degree of self-determination and non-self-determination (Figure 1).

Motivation
Reasons for doing something

Extrinsic motivation
- comes from outside an individual
- reasons to act are external
- behaviour is non-self-determined (e.g. avoiding punishment or receiving rewards such as good grades or money)

Intrinsic motivation
- comes from inside an individual
- reasons to act are internal
- behaviour is self-determined (e.g. act from enjoyment, satisfaction or interest)

Figure 1. Extrinsic and intrinsic motivation

Interest. Differentiation has to be made between students' motivation and students' interest. Unfortunately it is difficult to distinguish precisely between these two terms; clearly there is an overlap between intrinsic motivation and interest as you can be seen in Figure 1. However, motivation and interest do not have the same meaning, particularly since interest in this context differs from what we mean when talking about 'interest' in everyday language. For example, a friend might say: "Yesterday I watched an interesting movie." In general, this does not mean that your friend is really interested in this movie or similar movies. This does not mean that he or she is motivated to see this movie again and wants to know more about this movie, how it was produced, how many actors were involved, or how much trouble it was to film specific screens, etc.

Researchers have shown that interest is an important construct for describing and explaining processes and outcomes of learning in various educational settings (Hoffmann, Krapp, Renninger, & Baumert, 1998; Renninger, Hidi, & Krapp, 1992; Gardner & Tamir, 1989). Research has produced a variety of conceptualisations of interest and rather heterogeneous definitions; nevertheless the concepts relate to each other. One of the most prominent theories for the understanding of the concept of interest will be described in greater detail in the subsequent sections.

Attitudes. Before introducing important theories regarding motivation and interest, we should discuss briefly another term often mentioned in discussions about students' motivation and interests, namely attitudes (Osborne, Driver, & Simon, 1998; Osborne, 2003). There is wide agreement that the development of positive attitudes towards science in general and chemistry in particular should be regarded as an important goal of chemistry education (Koballa, 1988; Osborne & Dillon, 2008; Hofstein & Mamlok-Naaman, 2011). However, what is meant by the term 'attitude'? Oliver and Simpson (1988) suggested understanding of attitudes quite simply, as the degree to which extend an individual 'likes' something, e.g. chemistry or chemistry education.

Until recently, the term attitude in science education appeared to be a quite unclear conglomerate of different components. Koballa and Glynn (2007) highlighted in their review of the literature about attitudes in science education, that the term is often used interchangeably with other affective terms such as 'interests,' 'concerns,' 'beliefs,' 'curiosity,' 'opinions' or even 'motivation.' Among many components of attitudes overlapping with students' interests we can mention many factors that will influence students' motivation too. Among them we can find anxiety towards science, students' perception of the value of science knowledge, enjoyment of science learning activities, fear of failure in science courses, interest in enrolment in science related courses in school, etc. (Hofstein & Mamlok-Naaman, 2011). However, attitude is such an elusive term to define, that 50 years of research on understanding the various components of attitudes have resulted in non-conclusive results related to the issue (Hofstein & Mamlok-Naaman, 2011). It is for these reasons that this chapter focuses primarily on issues related to the development of interest and motivation in the teaching and learning of chemistry, as these two concepts are rooted more strongly in solid theoretical foundations.

Characteristics of interest: The Educational-Psychological Theory of Interest

One theory that conceptualises interest is the *Educational-Psychological-Theory of Interest* developed by Krapp (2002). Krapp's theory suggests that interest is not only an important condition for effective learning but is also central to an individual's personality. Interest is conceptualised as a specific relationship between an individual and a topic, an object, or an activity, which is characterised by positive emotional experiences and feelings of personal relevance. Interest-triggered actions are always self-intentional actions, which can assume the form of short-term interest for a particular object (situational interest) or a long-term preoccupation with something (individual interest) leading to a relatively strong personality trait (Renninger, 1998). This is illustrated by three examples provided in Figure 2.

One can see that interest can be considered and explained as being influenced by the situation and dependent on the character of an individual's psychological procedures. Interest is always connected with tasks or phenomena (in our example chemistry tasks). An object of interest can refer to concrete things, to other people, to activities, or to abstract-type ideas. Krapp (2002) suggested a special person-object-relationship. This relationship exists for a short period of time, therefore it is often resulting from situational interest or 'interestingness,' a character of the context, and this is nothing else than being motivated to do something for a (more or less short) period of time. Situational interest is triggered more suddenly by environmental factors; for example a motivating learning opportunity (Hidi & Bernhoff, 1998; Bolte, 2010). Situational interest can be the starting point from

A student Peter is deeply involved with the task you have just given him. Usually he doesn't like to participate in chemistry lessons. Possibly he is doing so only because the current situation (the context, bad weather, or little other amusement) or because he likes this kind of task. So in the present circumstances, Peter is interested in the topic. He has fun, the work is relevant for him and he learns it easily. Tomorrow, or in a different situation, Peter's cooperation might look completely different again. Peter shows a type of interest called situational interest.

For another student Paula the surrounding situation is not the determining factor. She is fully engaged in solving the problem and does not pay attention to possible other activities. Obviously, she enjoys solving chemistry problems and studying chemistry is important for her. She does not need (further) impulses from outside (for instance, being complimented by the teacher or looking for a good grade). She likes studying chemistry, possibly chemistry is one of her hobbies. Paula's motivation to study chemistry is obviously independent of the situation; it is permanent and seems to be part of her character. This type of interest is called individual interest.

Of course, a completely different case can be imagined. John finds chemistry lessons boring, stressful and "not cool" – regardless of which work has to be done. He often refuses to cooperate, is distracted and engaged with other things. He does not care what others (his chemistry teacher, his parents or his classmates) may think of his behaviour. As he says: "Chemistry is simply foreign to my nature." John is not interested in chemistry.

Figure 2. Examples for short-term and long-term interest (adopted from Streller & Bolte, 2012)

which to develop individual interest (Schiefele, 1998), but situational interest does not always lead to individual interest.

Interest related to person-object-relationships, as described in Figure 2, are always characterised by positive emotions, such as an optimal level of arousal, empathic content-specific emotional experience, and feeling of competence (Krapp, 2002). When we are self-intentionally engaged with matters relevant to us, we are psychologically affected, sometimes we completely forget about the time and the surroundings. This is an experience of flow (Czikszentmihaly, 2008). We experience joy, partly consciously, partly unconsciously. Interest-based acting gives pleasure and is accompanied by positive emotions. Even if we experience setbacks and frustrations, these positive emotions will remain predominant. Otherwise, we would lose interest in a matter, subject, task, or an activity.

Furthermore, actions of interest lead to further differentiation of cognitive structures. Interest has a tendency to let cognitive structures expand. This makes interest so important for learning. An interested person is not content with his current level of knowledge or abilities within the domain of interest. A third aspect of interest is the component referred to as its value to a person. We could say, the individual assigns positive value-related attributes to the goals, contents, and actions that are related to the domain of interest. If something were of an interest it would have a prominent position within the individuals' hierarchy of values (Krapp, 2002). Action based on interest always means that it is being done completely voluntarily (i.e. intrinsically motivated) and it is self-intentional. It is an end in itself and there is no need for external (extrinsic) motivation.

A further aspect which can help to define interest is the view that interest is part of a person's identity and character. In short: interests are distinguishing marks of our personality. They belong to us, they are important for us since the objects of our interests are of individual significance; they are of great relevance in our individual imagination of norms and values.

Interests are not carved in stone and are not based on genetic inheritance; interests can be acquired and they can change (Bandura, 1986; Wade, 2001), which is helpful from the perspective of teaching chemistry. This means that a chemistry teacher can stimulate, maintain and stabilise his students' interests and that interests can even be increased or intensified, respectively (Streller & Bolte, 2012).

Often, beginning teachers are surprised regarding the amount of knowledge students adopt in matters of interest to them, how capable they are in becoming increasingly competent if they are really engaged in something and how they practise and try to perfect their repertoire of acting. In doing all this, they gain cognitive differentiation without pressure or stimulation from outside (self-intentionality), they enjoy what they are doing and feel satisfied (emotional aspect), that all this is important and meaningful for them (imagination of norms and values). Therefore teaching chemistry should put special emphasis on the effort to stimulate, to bring forward, and to stabilise the interest of students to study chemistry.

Under certain circumstances the reasons for learning may be perceived as interest, however, this does not necessarily mean that interesting situations provoke students to develop interest. As interests are being acquired students might also develop interest in chemistry and studying chemistry if they repeatedly experience chemistry lessons that they find interesting. As found by Streller and Bolte (2012), it is unlikely that a single event of this kind, e.g. visiting a science centre, will be sufficient to provoke and to stabilise long lasting interest. Figure 3 summarises the different aspects of acting guided by interest.

Development of motivation and interests: The Self-Determination-Theory of Motivation

Several research studies refer to the question of how interests are developed individually (Hidi & Renninger 2006; Shah & Gardner, 2008; Ryan & Deci, 2000). The concept of internalisation and the connection between the development of interests and development of self-concept are highlighted as important factors and so will be the focus here. Both concepts can be used to provide recommendations for creating interest-promoting opportunities in chemistry teaching.

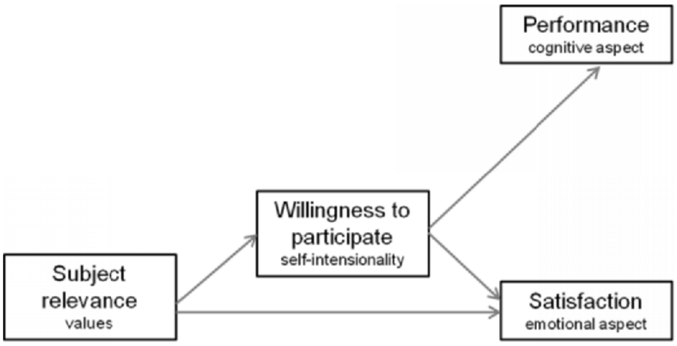

Figure 3. Characteristics of interest-oriented learning

Deci and Ryan (1985, 2002) offer a comprehensive answer to the question of how to develop interests and how to stabilise them. In their self-determination theory of motivation, Deci and Ryan created a concept of internalisation explaining how interest-determined actions can originate (Ryan & Deci, 2000). This concept is based on the assumption that each person wants (develops) his natural psychological needs for competence, relatedness, and autonomy to be met (Deci & Ryan, 1985). Competence means to be effective in dealing with the environment in which a person finds oneself, relatedness is the wish to interact, to be connected to, and experience caring for others, and finally, autonomy is the need to be causal agents of one's own life. These three needs appear to be essential for facilitating optimal function for a person's natural propensities for growth and integration, as well as for constructive social development and well-being (Ryan & Deci, 2000). Intrinsically motivated behaviour is mainly ascribed by the needs for competence and autonomy, while extrinsically motivated behaviour pertains to a relatively great extent to social relationships (Deci & Ryan, 1985). Applying the concept of internalisation, different aims of actions (developing intentions) can be understood and explained.

If an action is being experienced as choice, it is regarded as self-determined; if it is being experienced as externally regulated it is considered as non-self determined or controlled. The concepts "controlled" and "self-determined" can be understood as poles of a continuum: the continuum between extrinsic and intrinsic motivation (Figure 4). With the self-determination theory of motivation the separation of intrinsic and extrinsic motivation is being refuted. Instead of this, the focus is placed on the process of the development from extrinsic to intrinsic motivation. According to Deci and Ryan (1985) the development of extrinsic motivation can be defined as process of growing internalisation of intentions. This process is pushed by the same psychological needs (competence, autonomy, relatedness) as the development of intrinsic motivation.

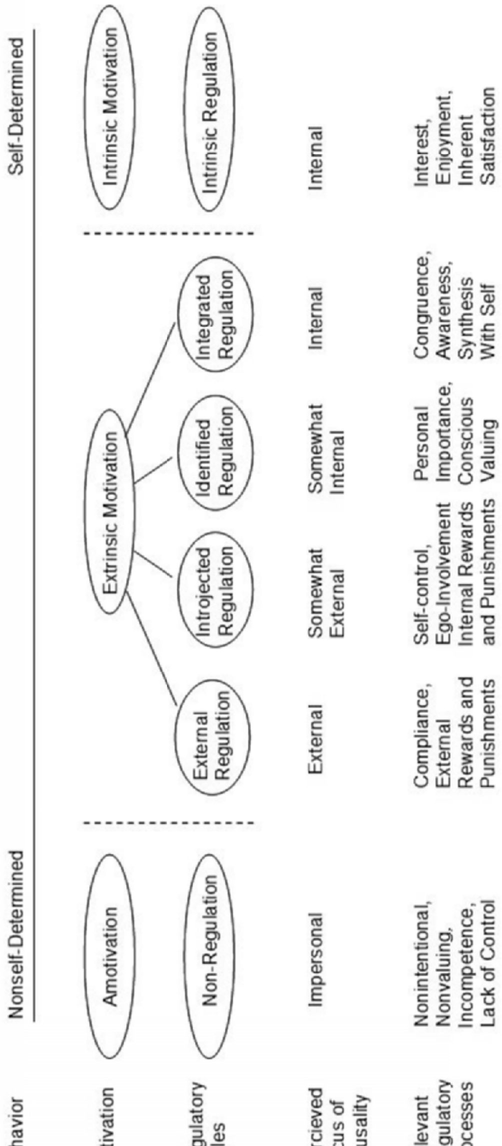

Figure 4. Various types of motivation in the continuum of self-determination (Ryan & Deci 2000)

At the far left of the self-determination continuum is amotivation. Amotivated people do not act or act without an intent. At the far right of the continuum is the state of intrinsic motivation. Between these two poles we find the extrinsic motivation, but differentiated into four classifications (Figure 4). The least autonomous forms of extrinsically motivated behaviours are referred to as being externally regulated. Individuals typically experience externally regulated behaviour as controlled where actions will only be carried out for being compliant or for avoiding punishment. The only reason to act is external pressure. This form of extrinsic motivation is normally contrasted with intrinsic motivation (Figure 1). In the stage of introjected regulation a person acts subject to internal pressure (because it is polite). This means that the person has already internalised external intentions, but not fully accepted them as one's own. A more self-determined form of extrinsic motivation is regulation through identification. The individual accepts the formerly external intentions as his or her own ones, and carries out an action because they consider the matter to be personally important, but they do not enjoy it. The integrated regulation is the highest stage of extrinsic motivation. The person not only accepts certain actions and intentions, but these are completely integrated with their sense of self. The regulations have been evaluated and fit with one's other values and needs.

The process of regulation is driven by satisfying the three needs (competence, autonomy, and relatedness). Learning environments, in which the teacher demonstrates sympathy for the learners, satisfy their psychological needs, and support the learners in becoming more and more independent will enhance the development of motivation based on self-determination. The corner stone of this development is experiencing freedom in one's actions, i.e. to have a choice in a certain action. Also, of great relevance, is the appreciation of one's own aim. The awareness of one's ego that influences a better quality of learning and brings forward the development of the individual character.

The MoLE (Motivational Learning Environment) Model

When combining both theories discussed so far (the pedagogic interest-theory and the self-determination theory of motivation), a complex instruction model can be derived (Bolte, 2001, 2010). This model consists of seven different variables:

– Comprehensibility/requirements,
– Opportunities to participate,
– Subject relevance,
– Content of the science subject (in general),
– Class cooperation,
– Individual student's willingness to participate and
– Satisfaction.

Between these variables, causal connections were assumed which were validated by statistical analysis (Bolte, 1995, 2006). Both, the theoretically sound assumptions and the empirically invested relationships between the important aspects of motivation led to the *Model of Motivational Learning Environments (MoLE)* (Figure 5).

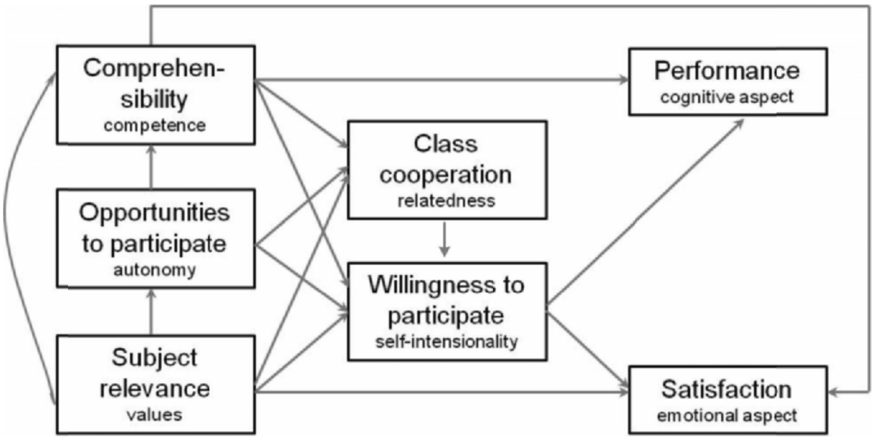

Figure 5. The model of a motivational learning environment

The first three independent variables (*comprehensibility, opportunities to participate* and *subject relevance*) rely upon the teacher's behaviour, whereas the four remaining dependent variables (*class cooperation*, *willingness to participate*, and *performance and satisfaction*) are reliant on the class in general and on the individual student. The variable *requirements/comprehensibility* describes the intellectual level of the instruction and the standards of the topics taught. It is well known based on theories of enhancement of motivation (Heckhausen, 1991), that setting a certain standard increases students' efforts and performance. A similar notion is that of high expectations. The variable *opportunities to participate* indicate to what degree the teacher is susceptible to students' ideas and opinions? *Subject relevance* indicates whether the students judge the topics chosen by the teacher to be relevant with regard to their everyday life. These three variables are likely to influence students' behaviour during their lessons. A suitable standard, a high level of relevance and the opportunity to participate are stimuli for an increase of the variables *class cooperation* and *student's willingness to participate*. Furthermore, a suitable standard results in an increase of student performance. A higher perception of relevance of topics presumably entails a higher satisfaction with the instruction. Finally, active *class cooperation* is a probable stimulus for an increase in the individual student's willingness to participate. The increase in his/her willingness to participate will also increase his/her performance and satisfaction (Bolte, 2006).

It is suggested, that applying this model to classroom situations, in our case chemistry education, can help the chemistry teacher in promoting motivation. In addition, using this model calls for balancing the intellectual requirements, choosing educational approaches which offer opportunities to participate actively in the classroom, and to relate science content and concepts with topics which are perceived to be relevant, meaningful, and important to the student (Bolte, 1995; 2010).

Insights into students' interests

In the last decades, many studies were conducted in order to obtain insight into the students' interests in science (Hoffmann et al., 1998). It is beyond the scope of this chapter to provide a thorough review of these studies. However, we will provide a brief overview about two respective studies; one regarding interests in science in general and the second regarding interests in chemistry in particular.

ROSE – Relevance of Science Education Project. The ROSE project is an international survey aimed at exploring the perception of relevance of school science education from the perspective of students. The focus of ROSE was on students' attitudes, interests and out-of-school experiences. The aim was to generate perspectives to enrich discussions about how to improve science curricula best

> To enhance students' interests in science and technology in ways that:
> 1. Respect cultural diversity and gender equity,
> 2. Promote personal and social relevance, and
> 3. Empower the learner for democratic participation and citizenship.
> (Jenkins & Pell, 2006).

ROSE was conducted among 15 and 16-year-old students in 46 countries all over the world. In each of the countries, 25 schools with classes of about 25 students were involved. The 625 students from each country received a questionnaire containing more than 245 items regarding different aspects (e.g. "What I want to learn about …" or "My future job …"). The ROSE was conducted throughout the academic years 2005 and 2006 (Sjøberg & Schreiner, 2006, 2010).

The questionnaire used in the ROSE study consist 106 Likert-type items e.g. "How interested are you in learning about the following?" The items cover a wide range of possible topics for science learning and reflect both content (like "electricity," "heat," "mechanics," "botany," "chemistry," etc.) and contexts ("social," "technical," "ethical," "practical," "theoretical," etc.). An example for such an item is: "How radioactivity affects the human body." The participants were asked to assess these items using a Likert-type scale from "not interested" (1) to "very interested" (4).

The overall picture shows that attitudes to science and technology among the young people are mainly positive. Sjøberg and Schreiner (2010) state that:

> in the richest countries young people are more ambivalent and sceptical and there is growing gender difference, with girls, in particular in the richest countries, being more negative (or sceptical, ambivalent) than boys.

Students in less developed countries express an interest to learn about nearly all the topics that are listed (Sjøberg & Schreiner, 2010).

The results of the English ROSE study can be used as an example (Jenkins & Pell, 2006). The overall measure of 'interest' is 2.47 for girls and 2.50 for boys. For girls, the priorities lie with topics related to the self, and more specifically to health, mind and well-being. When the boys were examined, there were strong levels of interest displayed towards topics associated with destructive technologies and events (Table 1).

Table 1. The five most popular (white background) and the five least popular (grey background) topics for boys and girls in England (scale 1 not interested … 4 very interested) (Jenkins & Pell, 2006, pp. 15-16)

Boys	***Girls***
Explosive chemicals (3.38)	Why we dream when we [are] sleeping and what the dreams may mean (3.47)
How it feels to being weightless in space (3.29)	Cancer, what we know and how we treat it (3.35)
How the atom bomb functions (3.24)	How to perform first-aid and use basic medical equipment (3.33)
Biological and chemical weapons and what they do to the human body (3.22)	How to exercise to keep the body fit and strong (3.20)
Black holes, supernovae and other spectacular objects in outer space (3.17)	Sexually transmitted diseases and how to be protected against them (3.11)
…	…
Plants in my area (1.82)	How petrol and diesel engine works (1.73)
How crude oil is converted to other materials (1.79)	How a nuclear power plant functions (1.72)
Detergents and soap (1.74)	Famous scientists and their lives (1.71)
Lotions, creams and the skin (1.70)	Symmetries and patterns in leaves (1.67)
Symmetries and patterns in leaves (1.42)	How crude oil is converted to other materials (1.51)

Although the distribution of 'interest' among boys and girls is significantly different, it is important to acknowledge that a high level of so called interest in a given topic by one gender does not necessarily mean that the same topic is of 'no interest' to the other. Many topics boys indicate strongly that they would wish to learn about are also interesting for girls but on a lower level and vice versa (Jenkins & Pell, 2006).

You may have recognised that the questions in the ROSE study focus mainly on single topics. In some cases they are combined with a context and hence not specific. In other cases the ROSE statements focus on certain fields, contexts and topics in general (such as "atoms and molecules" or "sex and reproduction") so that one may gain a global impression concerning students' preferences.

The IPN Interest in Chemistry Study. The goal of the "*IPN Interest in Chemistry Study*" (Gräber, 1998, 2011) "*was to find criteria to develop methods which could help to promote students' interests and motivate them to engage more deeply in science issues*" (Gräber, 2011, p. 3). In 1990, when this study was first conducted, more than 3000 German students participated (Gräber, 1998). Parts of this study were repeated 18 years later; more than 1200 students answered a short version of the original questionnaire (Gräber, 2011). Both questionnaires distinguish between three types of interest: interest in chemistry (example of an item: "How interested are you in learning more about how to make plastic from petroleum?"), interest in chemistry lessons (example of an item: "How much are you interested in chemistry lessons?"), and leisure interest in chemistry (example of an item: "When I find something in the newspaper about something we have heard about in chemistry class, I read it"). All items were assessed on a 5 point Likert-type scale from very interested to not interested. In addition to the types of interests there are some more variables which are covered in this investigation, e.g. self-concept or specific classroom characteristics.

The *interest in chemistry* construct is based on the assumption of a multidimensional object structure composed of the various categories related to topics, contexts, and activities (Figure 6). Seven topics were presented systematically in different contexts and linked to different activities. In the above-mentioned item we find a topic "plastics," a context "how to make something" and the activity "learn more about …." This construction of the items is important because when you ask about a topic in general, the question can have very different meanings to different individuals. If an individual is asked about his/her interest in dyes, it is possible that he thinks about indigo and wonderful colours, or about harmful and carcinogenic dyes. It is also possible, depending on the individual's background that he or she remembers extremely complex and difficult molecule structures. If one now combines the different topics with contexts and activities, it is more likely that one has similar associations. Using specific statistical methods (e.g. factor analyses) it becomes possible to 'filter' the assessments of the single categories (e.g. content/topic, context, activity).

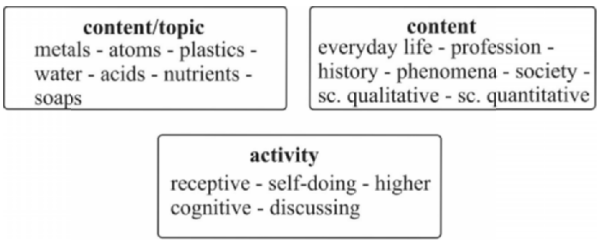

Figure 6. Interest in chemistry: Items are formed by combination of aspects from the three categories (7 topics, 7 contexts, 4 types of activities) – Example item: How interested are you in learning more about how to make plastic from petroleum? (Gräber, 1998)

Table 2. Agreement of girls and boys regarding topics, contexts and activities in chemistry lessons in % of students who marked "interesting" or "very interesting"

	Topics/contents in % agreement		***Contexts in % agreement***		***Activities in % agreement***	
girls	dyes	70	application (danger)	68	carry out experiment	*87*
	noble metals	55	household	60	watch film	*59*
	acids	53	application (use)	55	plan experiment	*56*
	soap	53	leisure time	50	watch experiment	*56*
	carbohydrates	50	phenomena	50	develop model	*56*
boys	acids	65	application (danger)	75	carry out experiment	88
	noble metals	55	application use	72	watch films	63
	atoms	52	phenomena	60	plan experiment	62
	metals	46	leisure time	57	watch experiment	62
	plastic	45	technical environment	55	express own opinion	38

The key findings from the *IPN Interest Study in Chemistry* (Gräber, 2011; see Table 2) can be summed up under the following categories:

– *Content and topics*: Girls and boys were both found to be 'interested' in socially relevant topics like pollution or power supply. Girls prefer topics they can personally relate to such as: hygiene, nutrition, or decoration. This result coincides with the findings of the ROSE study. Boys are more 'interested' in topics such as metals, mineral oil, or plastics.

– *Contexts*: The contexts "chemical application that can be of great use to us now and in future" as well as "chemical applications that can endanger us and the environment" were prioritised by most of the girls and the boys. These contexts illustrate a socio-scientific dimension and seem to be appropriate for promoting 'interest' in chemistry (see Chapter 1). The girls find the context chemistry in the household much more 'interesting' than boys. The technical environment context ranks at the lower end of the scale for girls and at the upper end for boys.

– *Activities*: In 2008, 87% of the girls and 89% of the boys indicated a substantial interest in making chemistry experiments. Both prefer to carry out the experiments by themselves. All the other activities belonging to the carrying out experiments category, like planning an experiment, explaining the observations, calculating and formulating equations were rated (significantly) lower. From the perspective of science education and the theories of learning carrying out experiments is not enough; experiments have to be planned, observed and explained (see Chapter 6). The study assumes that teachers do not spend enough time to solve a problem together with the students but just wait for a student to offer the right answer. Therefore, teachers frequently classify observations formulated by students as not being relevant. Thus, students can get the impression that their personal experiences are not taken seriously. In future, they may not try to explain their observations anymore but will try to guess the right answer. Furthermore, lessons usually draw the line too quickly from observations to symbolic equations – often in only one lesson (see Chapter 4).

– *Developments of interest in chemistry lessons*: When data gathered from 1990 and 2008 was compared it indicated a significant rating, on a high level, on the scale of interest in chemistry lessons for both genders (boys and girls). This result is encouraging. Gräber (2011) explains his findings by outlining the new approaches in German chemistry teaching, which focus more on the inclusion of everyday life contexts. Further analysis showed that in the survey in 1990 and in 2008 one variable is of considerable importance when explaining interest in science lessons and this is the principle of self-concept. Students with a high chemistry-related self-concept of their own ability are more interested in science lessons than students with a lower self-concept (see subsection self-determination-theory of motivation).

In conclusion, it is suggested that there are two effective ways that can be implemented by teachers to enhance students' interest. Firstly, through a balanced combination of content and context (see also Chapter 1), and secondly, through an appropriate methodical design of the lessons (see also Chapters 6, 7 and 8). Topics that are less attractive to girls and boys can be strengthened in their value for the students by being embedded in more relevant contexts (such as applications and socio-scientific issues; see Chapter 1) or being linked to activities which are enjoyable for the students (such as inquiry; see Chapter 6).

Theoretical suggestions to enhance motivation

It is beyond the scope of this chapter to discuss all the theories that underline the concept of motivation in the context of education. We selected those that have some relevance to the field of science education in general and to the chemistry teachers' classroom practice in particular.

While the Self-Determination-Theory of Motivation is the dominant theory for basic understanding of motivation in general, the picture concerning theories for understanding and enhancing motivation in the classroom is a bit more diverse. There are several suggestions related to practice-friendly theories of motivation related to education in general and science education in particular. One of them has been discussed above and it was illustrated how it led to suggestions for structuring chemistry lessons. These theories try to guide the teacher in the question: What can the teacher do to enhance his or her students' motivation to learn science in general and chemistry in particular.

Hofstein and Walberg (1995) suggested that in order to enhance motivation in the classroom there is a need: to create an environment in which (a) students are given opportunities to interact physically and intellectually with instructional materials whenever possible through handling, operating and practicing, (b) effort is made by the teacher to provide materials and instruction that gives reality and concreteness to scientific (in our case chemistry) concepts, and (c) teachers vary instructional strategies materials, and classroom practice with the aim of increasing effectiveness of teaching and learning by enhancing students' motivation. Three more practice-friendly models offering guidance to the teacher to create motivating learning environments in chemistry education shall be presented in brief.

The Model of Motivational Design. In 1983, Keller outlined four components of motivation with respect to learning environments: interest, relevance, expectancy and satisfaction. Upon these four components Keller and Kopp (1987) build a model of motivational design. Based on their model it is suggested that: attention, relevance, confidence, and satisfaction (ARCS) should be promoted in the learners in order to enhance their motivation. The ARCS-model sums up potential instructional techniques in the four domains that can be used and combined for promoting and sustaining motivation in teaching. The domains in the ARCS-model are:

- *Attention*: Attention can be enhanced using surprise or uncertainty to support interest. Curiosity should be challenged by posing questions or problems to be solved. Methods which can be used include pedagogies of active participation to get learners involved with the material or subject matter. Variety is requested to account for individual differences in learning styles. Humour, incongruity, conflict or inquiry might be used to activate thinking.
- *Relevance*: Relevance should be established. Strategies encompass telling the learner how the new learning will use their existing skills. It should become clear how the topic concerns the learner currently and in future, and how it matches their needs. It should be made clear what one can do with the learned knowledge, e.g. making the students the tutor of others, but also allowing them the choice to organise their work based on their interests and prior skills.
- *Confidence*: Confidence can be supported by helping students understand their likelihood for success. Objectives and prerequisites to understand performance requirements and evaluation criteria should be clear to the students. Instruction should allow for success that is meaningful by small steps of growth during the learning process. Positive feedback should be provided and the feeling that the learner's success is a direct result of their effort in learning.
- *Satisfaction*: Satisfaction can be developed and supported by rewards such as praise from the teacher. The learner should experience worth of the learning, e.g. by allowing them application of the acquired knowledge in a new setting.

In 2005, Feng and Tuan in the case of acid-base-chemistry teaching showed that orienting chemistry lessons along the ARCS-model can lead to raising motivation and achievement in chemistry classes.

The Six C's Model of Motivation. In 1995, Turner and Paris suggested another view on motivation. They described six components that can help to analyse whether a learning environment is motivating to the student. The more the six components are available to the student in the classroom the more motivating the learning environment might be:

- *Choice*: If the learning environment allows the student choices, e.g. which experiment to complete, in which sequence to accomplish tasks, or how to present results, these it is suggested will enhance their intrinsic motivation.
- *Challenge*: Work that is too difficult raises anxiety, whereas tasks that are too easy contribute to boredom. Therefore tasks should be near to or even slightly beyond the actual skill level of the students.
- *Control*: Settings in which the students are allowed to participate in decision-making, organisation of content, choosing team members and thus becoming responsible, independent, and self-regulated learners can contribute to motivation.
- *Collaboration*: Learning environments which are potentially motivating to the students are ones where students can share learning experiences and perspectives with each other through social interaction and cooperative work.
- *Constructing meaning*: If the students perceive the value of learning by understanding the meaning of it, their motivation to learn might increase.
- *Consequences*: If the learning is connected to positive consequences it can become more motivating for the learner, e.g. rewards, praise, successful experiments, or leading to an appreciated product by the learning process.

A model of learner motivational characteristics and pedagogies

In 1985, Hofstein and Kempa summarised the educational literature related to the aspect of enhancement of motivation in the context of school science. Their analysis appeared in suggestions for classroom action in two broad categories namely:

- Suggestions relating to the nature, structuring, and presentation of subject matter, and
- Suggestions concerning the nature of the pedagogical procedures and interventions to be adopted by teachers, as well as the climate of the learning environment to be established by the teacher.

This is still the state of theory today. There is not one single recipe (or set of recipes) to foster students' motivation and interest in chemistry education. Every student reacts individually to options given by teachers, be it the themes or methods (Häussler & Hoffmann, 2002; Hofstein & Kempa, 1985). The motivational precondition has to be as well considered as does the cognitive abilities of the learners. Hofstein and Kempa suggested that regular science class students will be different in their motivational traits: the achievers, curious, conscientious, and the socially motivated (Table 3).

Table 3. Relating instructional features to students' motivational characteristics

Type of activity	***Suitability/unsuitability***	***Examples***
Discovery/inquiry-oriented pedagogies and problem-solving	Suitable mainly for students with 'curiosity'-type motivational pattern. Insofar as problem-solving activities are likely to require students to engage in judgment and evaluation situations (both tend to involve 'high risk' taking), these are disliked by both 'achievers' and 'conscientious' students.	Inquiry-based learning in the laboratory as described in Chapter 6 or the example on the learning company approach from Chapter 7.
Open-ended , student-centred learning activities	Strongly preferred by the 'curious,' but not by other motivational groups who prefer clear teacher direction as regards educational goals.	Cooperative learning or the learning company approach as described in Chapter 7.
Formal teaching with emphasis on information and skill transfer	Preferred by 'achievers' and 'conscientious' students because low level of risk-taking is needed only.	Traditional instruction mainly involving frontal teaching as discussed in Chapter 7.
Collaborative learning activities	Suitable for learners with a strong social motivation pattern. 'Achievers' are likely to be opposed to an involvement in this type of learning activity.	Cooperative learning as described in Chapter 7 or computer supported collaborative learning in Chapter 8.

Hofstein and Walberg (1995) referred this relationship to different preferences and dislikes students most probably will have for particular modes of instruction in science education (Table 4). It is suggested that in planning instruction (teachers' PCK) science teachers should consider this relationship seriously. Such a view asks for varying the instructional approaches and pedagogies to align with the different needs the different students have.

THE PRACTICE OF CHEMISTRY TEACHING

General strategies

As discussed in the theoretical section of this chapter, science education research suggests that in order to motivate the students to learn chemistry a chemistry teacher should: Align the content with students' abilities and combine the topics with contexts which are relevant from students' view (see Chapter 1). Furthermore,

Table 4. Preferred modes of learning by students having different motivational patterns (Hofstein & Walberg, 1995)

Instructional feature	***Achievers***	***Curious***	***Conscientious***	***Socially motivated***
Nature and orientation of learning activities				
Obtaining information and skills	+		+	
Problem-solving		+		
Learning of laws and principles	+			
Learning by discovery		+		
Involvement in learning tasks demanding judgement and evaluation	-		-	
Control of goals, and organization of learning tasks				
Teacher control of task			+	
Student control of task		+		
Open-endedness of learning goals		+		
Teacher control of learning goals	(+)		+	
Learning in groups	-			+
Individualization of learning	-	+		
Evaluation of student performance				
Objective-competitive by teacher	+			(-)
Personal, individual by teacher			+	
Peer-group evaluation	-			+
Frequency of evaluation – often	+		+	
rare		+		

it is recommended varying the classroom learning environment by effective pedagogical instructional procedures to offer the students multiple opportunities to participate (see Chapter 7). These are two general ways teachers have to enhance students' motivation to learn science. In the following section we elaborate these ideas in more details.

Learning from context-based and socio-scientific issues. As mentioned before one can gain insights on which context is more or less interesting for students in general and/or for boys and girls in particular through the results presented in the ROSE study and the IPN interest in chemistry study. Many examples outlining how chemistry education is connected with issues and contexts which are interesting to the students can be found in the framework of European Commission FP6 and FP7 programmes. This programme funded many projects to develop and adapt existing teaching and learning materials which help to enhance science learning. In particular, the PARSEL (Popularity and relevance of science education for scientific literacy) and PROFILES (Professional reflection-oriented focus on inquiry-based learning and education through science) projects developed materials for teaching and learning chemistry and science. The PARSEL and PROFILES materials are published on the project websites on the internet and exemplary materials are available in many different languages (see in the Resources from the Internet section).

Varying the pedagogy. Science teaching is taking place in heterogeneous classes and we need to cater for all students with their different needs and different motivations. If we use varied-types of instructional procedures and techniques, many different types of students should be satisfied (Hofstein & Kempa, 1985).

To foster the students' self-concept teachers have to provide opportunities for the students to experience competence, to appreciate their chemistry class and to have a chance to interact socially (Bolte, 1995; Ryan & Deci, 2000). To facilitate this, the teacher should provide first hand experiences and offer the students opportunities to choose tasks they prefer. Problem-solving and learning by discovery is well liked by students, particularly if is connected to practical work, especially when the students are carrying out the experiments themselves (see Chapter 6). Also, independent work in small groups and other cooperative learning methods (see Chapter 7) can help to strengthen and enhance the students' self-confidence in solving tasks in chemistry.

Taking students' individuality into account. It is important to add that there is not one recipe to foster *the* interest of all students in science or to motivate them to learn science. Every student reacts individually and differently to options given by teachers, be it to the content or pedagogical methods (Häussler & Hoffmann, 2002; Hofstein & Kempa, 1985). That is why every chemistry teacher should pause for careful consideration and strive to match the instructional conditions to the characteristics of the learner. The motivational precondition has to be as well considered as does the cognitive abilities of the learners.

In our opinion, the best you can do is:

– Observe your students carefully while in class as you try out different methods.
– Reflect upon your lessons and talk about the lessons with your students.
– If possible discuss your lessons as often as possible with your colleagues.

Reflection and feedback either from the students or from trusted colleagues is helpful and necessary to optimise teaching practices and to adjust it to the needs and preferences of the students. Feedback from the students can be obtained by asking them or by using an instrument to assess motivation in chemistry education which will be introduced at the end of this chapter.

An example of how chemistry education can be designed to motivate the students

Within the frame of a university-school-cooperation, pre-service chemistry student teachers planned one week of lessons for 7th grade students using the topic air and air pollution. In the planning of these lessons, social contexts and an inquiry focus were placed high on the agenda, and given careful consideration. The following example reflects a sequence of 90 minutes on the impact of exhaust fumes on the human body (developed by Anne Schmidt, a student teacher at the Free University of Berlin, Germany, in 2009).

Scenario. Newspaper article about a "Driving Ban for 1.3 Million Cars in Beijing." This article describes the situation in Beijing in August 2008, shortly before the Olympic Games in this city. Because of the high air pollution in Beijing (pall of smog above the city) the organisers of the Olympic Games repeatedly imposed driving bans for cars, both before and during the games in order to improve the air quality. The athletes were very concerned about the poor air quality and expressed their fears to underachieve in their performances because of the poor air quality.

Preparation. The question posed was: What is the athletes' problem? The students formulated possible answers and assumptions about why the athletes were so concerned (e.g. polluted air harms the respiratory system, restrains oxygen absorption in the blood). The students then compiled, during class, conversation and through research the composition of air, breathing air and exhaust fumes as well as the relationship between respiration and the effect of exhaust fumes. As a concluding assumption, it was recorded that the proportion of carbon monoxide in the exhaust fumes has an impact on the athletes' blood by blocking the red blood cells and causing the blood to have less capacity of taking up oxygen. Accordingly, the athletes are not able to achieve maximum performance. These assumptions were then tested experimentally by planning a joint experiment: exhaust fumes have to be lead through blood. Carbon monoxide would change the blood's colour into light red. The students made a sample bag to collect exhaust fumes from a car. These exhaust fumes were then put through animal blood in a gas wash bottle. For comparison, air and breathing air were also put through animal blood. The colour change of the blood because of the exhaust fumes could not be reversed by subsequent perfusion of air. The students could thus conclude that carbon monoxide enrichment implies a loss of performance achievement due to a reduced oxygen uptake. Through the reference to the beginning of the lesson the students explained the athletes' concerns and also made personal references in some cases. Quote of a student: "*This happens to me, too, when I breathe in exhaust fumes*." In a concluding experiment by the teacher, it was shown that carbon monoxide in the blood can only be displaced by a high oxygen concentration. For this purpose, the carbon monoxide enriched blood was flushed with pure oxygen. At this point, carbon monoxide poisoning caused by inappropriate use of furnaces, the example of garage death and first aid measure is discussed.

Reflecting on the lesson described above. Let us align the suggestions derived in the theoretical part of this chapter to this lesson. The lesson plan chose a topic (air pollution) that this contains an environmental aspect with great acceptance by girls and boys. This topic was put into a context that is concerned with health and the own body, which especially appeals to girls. For boys, the technical reference to cars has great relevance. The context "Driving Ban during the Olympic Games in Bejing" also contains a socio-scientific dimension, namely the impact of driving bans on the people and the economy. Furthermore, the context of dangers of technical applications is considered. The students in this lesson had the opportunity to pursue different activities: reading, finding information, establishing assumptions and being able to explain them. They were able to plan an experiment, carry out this experiment in groups themselves, and develop a model in order to explain their findings. The conclusive class conversation about first aid regarding carbon monoxide poisoning illustrated again the reference to everyday life.

At the end of the whole sequence "air pollution," the motivational learning environment was assessed by means of a questionnaire (see Bolte, 2006). This was done in order to gain insight into students' perception regarding learning environment aspects such as relevance. The students claimed that they understood the content very well. The topics of the lesson sequence were perceived by the students as personally and socially more relevant to other chemistry lessons that they experienced in the past.

A checklist for stimulating motivation and interest in chemistry classes

The following checklist provides the teacher help in planning a lesson regarding the various motivational aspects. It might help to reflect on the lesson planning or may even provide guidance for enhancing motivation for chemistry learning.

- Is there support for the learner to become more independent?
- Is the content connected to a context about which the students to know more?
- Do the students have choices? Are they provided with opportunities to act freely or is everything controlled by the teacher?
- Is the context relevant for both, girls and boys?
- Are there aspects from every-day life (real life experiences) and are the issues students dealing with socially relevant?
- Do the activities vary to attract different students?
- Have you provided your students with first-hand experiences?
- Have you provide opportunities to wonder?
- Are there discussions and reflections offered in the lesson regarding the social importance of the content?
- Is the content connected to the application of science, to students personally, or to the human body?
- Can the students recognize the use and benefit of the content for their future?
- Are varied types of instructional techniques used?
- Do you provide support for learners to enhance their self-concept?

How to assess motivation in chemistry education? – An example

One way to assess motivation in chemistry education is using the "Questionnaires for the Assessment of the Motivational Learning Environment (MoLE)" developed by Bolte (1995, 2006). This questionnaire has been successfully adapted in several investigations to evaluate specific approaches to science education research among them a longitudinal study on young students' interest development in science learning (Streller & Bolte, 2012).

The MoLE-Questionnaire was designed for a systematic analysis of the students' perceptions of the actual classroom learning environment and also the preferred one. The questionnaire is based on the pedagogical interest theory, on the self-determination-theory, on theories of achievement motivation (see above), and on reflections from the field of classroom and learning environment research (Fraser, 1989). These various concepts of motivation and interest and the results of research on learning environment served as a basis for the development and validation MoLE-Model discussed above.

The idea behind the application of the MoLE-Questionnaire is to assess students' motivational pattern in their chemistry classes and also to evaluate information about how they wish their chemistry lessons should be. Therefore, the MoLE-Questionnaire consists of at least two different questionnaire versions; namely the real- and the ideal-version.

– The real-version investigates the current characteristics of the instruction in general, and
– The ideal-version investigates the desired characteristics.

Beside these two versions a third version was developed which focus on one specific chemistry lesson. This version was named as the "Today"-version.

All the three versions focus on the same seven variables of the MoLE-model. Every 'aspect' (variable) contains two items. There is a seven point rating scale to estimate the 14 items of each of the questionnaire versions. The statements which correspond to our ideas about a "good" science lesson are coded with high numerical values ("7" to "5"). Negative statements receive low numerical values (between "1" and "3"). The scale value "4" corresponds to a "neither-nor estimation." Figure 7 gives an example from the variable "comprehensibility/ requirements."

Item No. 3 in the Real-version:
The topics in chemistry lessons are...
very difficult for me to understand □ □ □ □ □ □ □ *very easy for me to understand.*

Item No. 3 in the Ideal-version:
I wish the topics in chemistry lessons to be...
very difficult for me to understand □ □ □ □ □ □ □ *very easy for me to understand.*

Item No. 3 in the Today-version:
The topics in chemistry lessons today were...
very difficult for me to understand □ □ □ □ □ □ □ *very easy for me to understand.*

Figure 7. Sample items from the three versions of the MoLE-questionnaire

With the help of the MoLE-Questionnaires one is able to collect data concerning the specific learning environments of a class by focusing on the three following perspectives; for example:

– On the students' perceptions and assessment of the and/or of their learning environment in general,
– On the students assessment how they would like the motivational leaning environment in their science lessons to be, and
– On the assessment of students, how they perceive a specific (a just experienced and/or tried out) science lesson.

To obtain this specific insight into the assessment and the development of the motivational learning environments the teacher can ask the students at different times, e.g.:

– Before the start of your instruction the students should be questioned on how they, looking back at their previous science lessons, regarded the motivational learning environment in general (therefore you would use the Real-version) and how they would like the motivational leaning environment in their science lessons to be (use of the Ideal-version).
– In the course of your instruction (for example if the teacher tries out a specific approach, teaching/learning methods, special student centred topics or materials) the teacher may use the Today-version to ask the students to evaluate how they, looking back at the just experienced science lesson, regarded the motivational learning environment specifically.
– At the end of the lessons plan or an instructional period the students are asked to reflect how, looking back at all the last science lessons, they regarded the motivational learning environment. This course of action provides insight into the motivational learning environment during past lessons. This can offer insights into the lessons before the intervention and after the chemistry lessons in general or into specific lessons you planned for the purpose of motivating you students. Additionally, statements can be made on how the students would generally like their science lessons to be. The comparison of the data from each of the questionings provides an insight into several different aspects. This can be, for example, in how far "wish" and "reality" coincide when considering the science lessons, which is a really good indicator of the motivational condition in classes. More information about the MoLE-model and the related questionnaires can be found on the Internet (see Resources from the Internet below).

SUMMARY: KEY SENTENCES

– Interest, attitudes, and motivation are different constructs. Interest is a specific type of motivation towards a topic or activity. Motivation is a precondition for the development of an individual and for sustainable interest. Attitudes overlap with these two and are influenced by both constructs. Interest and high motivation, or at least positive attitudes towards chemistry and chemistry teaching, will help to enhance students' engagement in chemistry classes and thus might increase their achievement in learning.

– There are three main variables teachers have to be cognisant of in order to motivate their students. These are relevance, offering opportunities to participate, and comprehensibility. There are three main factors to explain the development of motivation and interest, these are: competence, autonomy, and relatedness.
– Motivation and interest in school science can be enhanced by changing the nature, structuring, and presentation of the subject matter, and related pedagogies, as well as the climate of the classroom learning environment. Even if the topics and contents are not very interesting for students, teachers can increase the motivation to learn by combining those topics with relevant contexts and attractive activities.
– There are no clear-cut and precise recipes regarding creating of motivating learning environments, with the goal in mind of enhancing students' interest in science and science learning. The most appropriate starting point for increasing students' motivation and interest are the students themselves. Teachers can discover what their students' interests and attitudes are through interacting with them and investigating and valuing their opinions.

ASK YOURSELF

1. Give short definitions of the concepts of interest, motivation, and attitudes. Explain their common feature and differences.
2. Explain the differences between intrinsic and extrinsic motivation. Write down each three instructional strategies for the promotion of both forms of motivation, intrinsic and extrinsic, in the chemistry classroom.
3. Line out at least five instructional strategies to promote motivation in the chemistry classroom.
4. Outline a list of what we know based on research regarding which topics, related to chemistry education in lower secondary classes, the majority of students might find interesting

HINTS FOR FURTHER READING

Hoffmann, L., Krapp, A., Renninger, A., & Baumert, J. (eds.) (1993). *Interest and learning*. Kiel: IPN. The book offers a comprehensive overview about different theories towards the issue of interest and its connection to learning achievement.

Koballa, T. R., & Glynn, S. M. (2007). Attitudinal and motivational constructs in science learning. In S. K. Abell & N. G. Lederman (eds.), *Handbook of research on science education* (pp. 75-102). Mahwah: Lawrence Erlbaum. This chapter sums up available models and theoretical resources on students attitudes and motivation and leads to implications for research, policy and practice.

Hofstein, A. & Mamlok-Naaman, R. (2011). High-school students' attitudes towards and interest in learning chemistry. *Revista Educacion Quimica en Linea*, *22*(2), 90-102. The paper discusses issues related to developing attitudes in the context of chemistry learning.

Hofstein, A., & Kempa, R. F. (1985). Motivating strategies in science education: Attempt of an analysis. *European Journal of Science Education*, *3*, 221-229. The paper discusses a very early approach to different students' motivational patterns and defines four types students' preferred modes of learning. It suggests that different students need different teaching methods and thus calls the teachers to vary the teaching methods.

Trowbridge, L. W., Bybee, R. W., & Powell, J. C. (2004). *Teaching secondary school science* (8^{th} edition). Chapter 18: The psychological basis for effective science learning. Upper Saddle River: Pearson Education. The chapter discusses the influence of different psychological factors and principles that might be used to raise motivation and achievement in science education.

Bolte, C. (1995). Conception and application of a learning climate questionnaire based on motivational interest concepts for chemistry instruction at German schools. In D. L. Fisher (ed.), *The study of learning environments*, Vol. 8 (pp. 182-192). Perth: Curtin University. The chapter discusses the development and application of the questionnaire on motivation discussed earlier in this chapter.

RESOURCES FROM THE INTERNET

Pearson Assessment: *www.pearsonassessments.com/hai/images/tmrs/Motivation_Review_final.pdf*. This document provides a concise review of the literature concerning motivation.

Self-Determination Theory of Interest: *www.psych.rochester.edu/SDT/*. This website presents a brief overview of self-determination theory of interest and provides resources that address important issues such as human needs, values, intrinsic motivation, development of, motivation across different cultures, individual differences, and psychological well-being. You will find publications, questionnaires and more.

ROSE: *roseproject.no*. The website allows for insights into the international ROSE-study on relevance and interest in science education and allows access to findings from a lot of different countries.

PROFILES: *www.profiles-project.eu*. and *www.parsel.eu* You can find many teaching materials in English and several other languages which were developed with the aim of implementing more motivating curricula and pedagogies into science teaching.

MoLE: *www.chemie.fu-berlin.de/didaktik*. The MoLE instrument in its different versions and a detailed description of its use can be found here. Access to issues of the MoLE instrument also can be accessed via *www.profiles-project.eu*.

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ONNO DE JONG, RON BLONDER & JOHN OVERSBY

4. HOW TO BALANCE CHEMISTRY EDUCATION BETWEEN OBSERVING PHENOMENA AND THINKING IN MODELS

The first part of the chapter aims at offering some general background information about multiple meanings and models in chemistry and chemistry education. A number of students' difficulties in understanding these issues and factors that offer insight in their difficulties are also given. The second part of the chapter aims at providing three clusters of useful suggestions for the practice of teaching. The first cluster consists mainly of content-related suggestions for teaching multiple meanings and models, while the second cluster mainly covers student-related suggestions for teaching these issues. The third cluster regards suggestions for identifying students' (alternative) conceptions after teaching. Some suggestions are rather specific while others are more general; the latter allows teachers to adapt and elaborate them for use in the specific situation of their own classroom.

THEORETICAL BASIS

In a junior secondary school, the following discussion happened:

Teacher:	*Water can be decomposed into hydrogen and oxygen. These products are elements, that is, they are non-decomposable substances.*
Student:	*Non-decomposable? I do not understand. These elements consist of H_2 molecules and O_2 molecules that can split up ... uh ... into atoms.*
Teacher:	*Yes, but you have to know ... uh, ...*
Student:	(interrupting) *Understanding chemistry is often so hard ....*

Educational framework

Chemists describe reactions in terms of disappearance and appearance of substances, in terms of rearrangements of atoms, in terms of reaction equations expressed in symbols, in terms of processes of breaking and forming of bonds, in terms of energy changes, in terms of …. To put it briefly, chemists are familiar with using multiple meanings, also regarding other topics than chemical reactions.

I. Eilks and A. Hofstein (eds.), Teaching Chemistry – A Studybook, 97–126.

They are also familiar with models as important tools for describing chemical topics as well as for explaining and predicting them. In chemistry education, students have to learn multiple meanings and models but it is well-known that many of them have difficulties in understanding them. This is a challenge for their chemistry teachers. Unfortunately, a lot of them, especially student teachers and early-career stage teachers, often encounter difficulties in teaching multiple meanings and models. The present chapter aims at supporting teachers to overcome these problems successfully.

Before addressing the issues of multiple meanings and models, a concise overview of the educational framework is presented. This is formulated in terms of three dominant and interrelated points of view.

According to the *social constructivist* perspective, learning is a dynamic and social process (see Chapter 7) in which students actively construct meanings from their actual experience in connection with their prior understanding and the social setting (Driver, 1989). Knowledge and learning are considered as fundamentally situation based (see Chapter 1). This viewpoint emphasises the importance for chemistry textbooks and classroom practices to take into account students' authentic ways of reasoning.

According to the *socio-cultural* perspective, education is an enculturation process. Learning is considered as a change from a particular socio-cultural environment containing students' everyday life knowledge and experiences to a new socio-cultural environment containing school chemistry experiences and knowledge (Vygotsky, 1986). This transformation also includes a change of language: old terms get new meanings. In addition to the former perspective, this viewpoint also emphasises the importance of using adequate language in chemistry textbooks and classroom practices (see Chapter 5).

According to the *conceptual change* perspective, learning is a cognitive process of change of conceptions. Students will incorporate new conceptions with existing conceptions when they conceive them as intelligible, plausible, and fruitful, but they will block them when they see them as conflicting with their existing conceptions (Posner, Strike, Hewson, & Gertzog, 1982). In the latter case, conceptual change can be realised by a stepwise process of lowering the status of the blocking conception followed by raising the status of the new one (Hewson & Thorley, 1989). When students are confronted with new ideas evoking a cognitive conflict in them, this viewpoint implies that teachers use students' dissatisfaction for stimulating them to discard the blocking conceptions or limit their use in favour of adopting new conceptions that are also intelligible but more plausible and fruitful.

All three viewpoints acknowledge the important influence and role of the initial conceptions that students have when they are involved in learning. Students often use them for developing new conceptions, for example, when explaining chemical phenomena. It is well-known that students' conceptions do not always correspond with those agreed upon by the scientific community. Their alternative conceptions often create difficulties in understanding chemistry concepts and processes.

The problem of alternative conceptions can be confronted in several ways. The social constructivist and socio-cultural perspectives highlight the importance of negotiations about meanings in the classrooms, for instance, students can exchange their own explanation of an observed phenomenon with those of peer students and discuss them with each other and the teacher for developing new conceptions (see Chapter 7). This is not as simple as it may appear because many alternative conceptions are deeply rooted in students' ideas about everyday life and their experiences and, for that reason, they are considered by students to be reliable.

The conceptual change perspective indicates the importance of creating cognitive conflicts for students but this is also not a simple endeavour. It requires a teaching approach that starts to create enough dissatisfaction with existing conceptions to change these conceptions. Moreover, the evoked conflict should be sufficiently relevant for students to motivate them for changes. Even then, it is questionable if students completely discard their alternative ideas and fully substitute them for others. Many conceptions tend to be context-dependent and students are able to use their alternative conceptions in daily life and their learned conceptions in school only.

Regardless of this, students' alternative conceptions exist and should be taken into account when teaching chemistry.

Multiple meanings in teaching and learning chemistry

Johnstone (1993) has presented a very influential analysis of the nature of chemistry by distinguishing three related domains of meaning: the macroscopic domain, the submicroscopic domain, and the symbolic domain. Their relationship is depicted in Figure 1a.

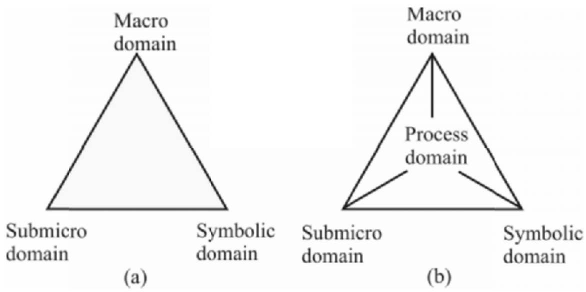


Figure 1. Relationship between domains of meaning: (a) basic version, (b) extended version

The *macroscopic domain* (hereinafter shortened to macro domain) mainly deals with substances and chemical phenomena that can be observed, smelled, and so on. For instance, sodium chloride (the main component of table salt) will be described as a white or colourless crystalline solid with a characteristic taste and the property to dissolve in water.

The *submicroscopic domain* (hereinafter shortened to submicro domain) mainly deals with particle entities, especially atoms, molecules, ions and electrons, and their arrangements. For instance, the constituent particles of solid sodium chloride can be described as ions of sodium and chlorine that are arranged in a regular ionic lattice.

The *symbolic domain* mainly deals with representations in terms of formulas, reaction equations, charge signs, and the like. For instance, the dissolving of sodium chloride in water can be described as $NaCl(s) + H_2O(l) \rightarrow Na^+(aq) + Cl^-(aq)$.

Dori and Hameiri (2003) proposed an extended version of Johnstone's triangle of meanings by adding a fourth domain (see Figure 1b).

The *process domain* mainly deals with the way any reaction occurs, such as processes of breaking and forming of bonds, energy changes, and so on. It can be related to each of the other three domains for acquiring a deeper insight in chemistry. In the dissolution example, this domain deals with disruption of the ionic lattice by water molecules and rearrangement and hydration of ions leading to an endothermic reaction (ΔH is positive).

Models and modelling in chemistry

A model is usually defined as a simplified representation of a target (i.e. object, substance, phenomenon, process) which concentrates attention on specific aspects of it (Ingham & Gilbert, 1991). This description implies that there are certain similarities as well as differences between model and target. For example, movements of small balls in a box can represent the movements of molecules of a liquid in a bottle, but there will be air between the balls while this is lacking between the molecules.

The main function of models is to express meanings by providing descriptions of the target, especially when it cannot be observed or measured directly, and by providing explanations and predictions regarding the target. Models are considered to be powerful when they are applicable in a range of contexts and for many purposes. For instance, the idea of particles is very powerful because it is fruitful used for describing chemical reactions qualitatively as well as quantitatively and for explaining and predicting many chemical processes. Models are not simple copies of reality but serve the development and testing of ideas. Thus, models are very useful tools in the communication between chemists through visualising topics, for instance by using ball-and-stick models of molecules or computer-based animations of processes (see Chapter 8). The use of models is also very important in theory development and problem solving.

Models can be designed, tested, revised and replaced. These activities are called modelling. When designing models, scientists have to find a compromise between the similarities and differences with the target. This process is guided by empirical data or theoretical notes with respect to the target and leads to a provisional model that is tested in a following step. This testing can be done through an empirical experiment or through a 'thought experiment.' The results indicate whether the model can be maintained or not. If not, it should be revised or replaced by another model. A well-known example of modelling is the development of the atomic model in the last centuries, from the ‘indivisible particles’ model in the 5th century BC (Democritus) towards the ‘sphere’ model in 1808 (Dalton), the ‘currant bun’ model in 1897 (Thomson), the ‘nucleus’ model in 1911 (Rutherford), the ‘orbit’ model in 1913 (Bohr), and more recent quantum mechanics models.

Modelling uses only the minimum of assumptions. For instance, in the 1920s the famous scientist Russell was faced with explaining the structure of alpha particles. He knew that they had a charge of +2 and a relative mass of 4. At that time, chemists had only knowledge of two kinds of sub-atomic particles, viz. protons and electrons; the empirical-based idea of neutrons was born in the 1930s. Russell pondered that the alpha particle was made up of 4 protons and 2 electrons. This model was satisfying because it explained the charge and the mass by using well-known particles. He dismissed the assumption of an unknown particle (charge 0, mass 1), which would make it possible to have an alpha particle consisting of two protons and two neutrons (the current model).

Models can be classified in several categories (Justi & Gilbert, 2000, 2002; Taber, 2008):

– *Mental models* are the result of internal cognitive activities and are, by their very nature, private and inaccessible to the external world. When they are taken into the tangible world for discussion, they are called *expressed models*. As soon as consensus is reached, they are called *consensus models*. This category of models is called s*cientific models* in the world of science.
– *Curriculum models* are the often simplified versions of scientific models that are incorporated in chemistry syllabuses as desirable knowledge. *Teaching models* are constructed for or by chemistry teachers to help them to communicate the curriculum models to students. Well-known examples of teaching models are *analogical models* that are designed by mapping similar features from the target onto a real world object or event, for instance dancing students are like moving and colliding molecules (see Chapter 7).

Both scientific and teaching models can be expressed in a variety of representation modes (Boulter & Buckley, 2000):

– *Material models* such as coloured plastic molecular scale models (ball-and-stick models, space-filling models),
– *Visual models* such as pictures of atoms or molecules, reaction rate diagrams of reactant concentration versus reaction time, and computer-based animations of processes,
– *Verbal models* such as oral expressions, written texts, analogies and metaphors,
– *Symbolic models* such as formulas of atoms or molecules (e.g. H_2 or H - H or H : H) and chemical reaction equations,
– *Mathematical models* such as the Arrhenius equation for chemical kinetics and the equation of the equilibrium constant (e.g. $K_{eq} = [C]^r \cdot [D]^s / [A]^p \cdot [B]^q$), or
– *Combined models* such as a text explanation of a phenomenon with a related diagram or a concept map including text and formulas.

Students' difficulties in understanding multiple meanings and models

Multiple meanings and models are not easy to understand for many school students. Their difficulties are reported in a range of empirical studies. A large collection of these studies can be found on the site: www.card.unp.ac.za. Based on information from this site, a number of typical conceptions that hinder understanding of chemistry are selected and presented in the next sub-sections. Regarding the issue of multiple meanings, the selection is focused on difficulties in understanding relations between domains of meaning. These difficulties are clustered in three groups. For each group a large number of difficulties have been reported, therefore, the selection is mainly restricted to the problematic understanding of the topic of the particulate nature of matter because this is a broad and fundamental topic in chemistry. Students' difficulties are presented as alternative conceptions that are elaborated by one or more specific examples. This presentation is followed by students' difficulties with models that are also formulated in terms of alternative conceptions and examples of them.

Difficulties with the relation between macro domain and submicro domain.

– *Solid matter made up by particles that are in close contact without space*. Macroscopic properties are explained by attributing these properties to individual particles. Students often believe a single atom of copper has a brown colour and a single molecule of chlorine has an irritating smell. They also reason that individual molecules of solids are hard while individual molecules of gases are cloud-like, and, more in general, they think that individual particles can expand, contract, melt, evaporate, condense, and so on.
– *Matter is continuous but there is space between the particles that is filled with something*. Macroscopic properties are explained by referring to this space. Students may think that the particles are additional to the substance and that the substance itself is in the space between the particles or they argue that the space is filled with air, so, gases can be compressed because air is compressible.
– *In electrochemical cells, electric current consists of flow of electrons, also in the electrolyte*. Some students believe that electrons float in the electrolyte and are able to move through the electrolyte when the electric circuit is closed. Others think that electrons move by a leaping action from one ion to another.

Difficulties with the relation between symbolic domain and macro or submicro domain.

– *Formulas only represent particles, even when a macro symbol is added.* Students do not interpret $Cl_2(g)$ as a representation of the substance chlorine in the gaseous state but as a representation of a single molecule in the gaseous state.
– *Formulas of compounds do not represent coherent clusters of particles.* Students may consider the formula H_2O as consisting of H_2 and O, that is, they draw a diatomic molecule of hydrogen and at some distance an atom of oxygen or they draw H_2O as three separated atoms.

– *Formula coefficients are equivalent to subscripts in a formula or function as multipliers of the subscripts. Subscripts are not fixed numbers.* Some students indicate that $2SO_2$ means: two atoms of S and two atoms of O and draw $3H_2$ as a series of six linearly linked hydrogen atoms. They also balance a reaction equation by changing subscripts in formulas of reactants or products instead of coefficients.

Difficulties with the relation between process domain and other domains.

– *When substances react, the breaking of bonds releases energy.* Students often believe that energy is stored in bonds and goes out at bond breaking; the forming of bonds requires input of energy.
– *When substances react, covalent bonds break more easily than ionic bonds.* Students tend to justify this alternative conception by reasoning that many molecular substances have lower melting points compared to ionic substances.
– *The dissolving of ionic substances in water means that the ionic molecules split up to give separate ions or stay as the solvated entities.* Students often reason that ionic substances consist of discrete molecules made from uni-directional bonded ion-pairs. In the case of solvated ionic molecules, they reason that the weaker bonds (often seen as Van der Waals forces) between ionic molecules have been broken.
– *Reaction equations indicating changes of particles' charge always represent redox reactions, while equations without charge of species do not refer to this type of reactions.* Some students do not interpret $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$ as a precipitation reaction but as a redox reaction (change of charges), while they do not recognise this type of reaction when they interpret $2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)$.

Difficulties with models.

– *Models are exact small-scale copies of reality.* Students do not tend to consider models as tools for understanding that can be revised or replaced when necessary. They also do not see models as a compromise between similarities and differences between model and target.
– *Macro models of a topic are more preferable than the related submicro models.* Students often prefer to interpret acid-base reactions using the (first taught) Arrhenius model (acids and bases defined in terms of substances) and not the (later taught) more general Brønsted model (acids and bases defined as particles). They also often prefer to interpret redox reactions using the oxygen model instead of the more general electron transfer model.
– *Models can consist of a mix of parts of different models leading to internal inconsistencies (hybrid models).* In case of a reaction between HCl and NaOH in aqueous solution, some students indicate HCl as the acid and OH^- as the base. Others identify H_3O^+ as the acid and NaOH as the base. They mix a part of the Arrhenius model with a part of the Brønsted model.
– *The validity of models has no clear limitations.* Students often reason that addition of a solid to a heterogeneous system of this solid that is already at

equilibrium with its dissolved ions will cause more ions to dissolve. This application of the Le Chatelier's Principle exceeds its validity.

– *The meaning of a model is not plausible.* In the context of models of redox reactions, students consider the value of an oxidation number as equal to the value of the charge of the related ion. However, for many of them this model is no longer plausible as soon as they apply this model to particles as H_2O and H_2O_2. In the case of H_2O, they agree that the oxidation number of H = +1 and O = –2 like the charges of the ions. But in the case of H_2O_2, they disagree because oxidation number of H = +1 and O = –1, and they believe that oxidation numbers have fixed values.

Factors explaining students' difficulties

Several factors contribute to the presence of students' problematic understanding of multiple meanings and models. Factors that offer particular insight in these difficulties are given below. They are clustered in three categories: (i) student, (ii) teacher/textbook, and (iii) curriculum.

The student factor: Mismatch between everyday conceptions and scientific conceptions. Students bring their everyday life ideas and experiences into the classroom but their notions are often different from the commonly accepted scientific concepts that are taught. For instance, students conceive matter to be continuous and, as a consequence, the idea of vacuum in matter is counter-intuitive for them. It will also be self-evident for them that particles are parts of a substance, so, atoms will be the smallest particles that still have the same properties as the substance itself such as colour and smell.

Another example regards students' ideas about chemical bond energy. Their alternative conception that the forming of bonds requires input of energy can be influenced by their experience that energy is needed for building structures or, in the context of human relationship, for the forging of bonds between persons (Boo, 1998). Their other alternative idea, namely that energy is stored in bonds, which is released when bonds break, can be based on the general everyday opinion that fuels and foods contain energy.

When students have to learn about acids, they often have difficulties with accepting that water molecules can function as an acid (according to the Brønsted model) and when they have to learn about redox reactions they feel that the reaction between magnesium and a solution of hydrogen chloride does not belong to this type of reaction because of the absence of oxygen.

To sum up, students can encounter conceptual difficulties due to conflicts with many intuitive ideas that they hold. These ideas have deep roots in their everyday life and, for that reason, are considered to be reliable. This will contribute to enlarge encountered difficulties.

The student factor: Demands of abstract reasoning and the use of complex conventions. Chemical reactions are not only taught as transformations of substances but also as rearrangements of atoms including the breaking and forming of chemical bonds. However, many students encounter difficulties to mentally jump from the macro meaning to the submicro meaning and reverse (Solsona, Izquierdo, & De Jong, 2003). This requires abstract reasoning and this ability is difficult for many students, especially because of the abstract character of many relevant concepts such as force, heat, atomic structure, and bond energy.

Jumping to the symbolic domain requires even more abstract reasoning and, moreover, the use of complex notation conventions. Not surprisingly, this also evokes a lot of difficulties. Students tend to ignore the submicro models that give meaning to chemical symbols (Yarroch, 1985). This can foster students' alternative conceptions of formula subscripts and coefficients (see the former section) and will contribute to conceive balancing chemical equations as mainly mathematical manipulations of symbols.

In conclusion, students can have difficulties with coping the high demands of abstract reasoning and the use of complex conventions.

The teacher/textbook factor: Expertise as a source of students' difficulties. Teachers are familiar with the relations between domains of meaning and are mentally able to quickly switch between the four domains in a routine and implicit way. However, teachers may switch so fast between the domains that it will hinder students to develop a proper decision when something has meaning in a macro domain and when in another domain. Teachers may also show a dominant focus on meanings in the submicro and symbolic domain only which will hinder students to connect these meaning with those in the macro domain properly (De Jong & Van Driel, 2004).

Expertise of textbook authors can also contribute to students' difficulties. For instance, many textbooks introduce formulas without justifying the way of noting. The formula of a salt as silver chloride is introduced as AgCl without justifying the absence of signs of charge although the particles involved in the precipitation reaction equation are presented as Ag^+(aq) and Cl^-(aq). This lack of justification promotes the tendency among students to consider this reaction as a redox reaction, and, more in general, to consider chemical formulas as algebraic expressions. In the case of AgCl and other salts, it also contributes to enhance students' alternative conception of the existence of molecules as constituent particles of ionic substances.

In conclusion, expertise of teachers and textbook authors can be a source of difficulties for students to develop a proper understanding of relations between domains meaning.

The teacher/textbook factor: Ignoring students' alternative conceptions. Teachers are often ambivalent towards the importance of students' alternative conceptions to their teaching (Sequira, Leite, & Duarte, 1993). On the one hand, they support the notion that teaching for meaningful learning implies that students construct, apply, and revise their own conceptions; on the other hand, they do not value students' own ideas because they see them as barriers for acquiring proper scientific knowledge. The latter viewpoint stimulates a 'top-down' classroom teaching approach. For instance, teachers introduce a concept by conducting an experiment and prematurely tell their students what they are supposed to observe and which submicroscopic explanations correspond to these observations (De Jong, Acampo, & Verdonk, 1995). This approach is often also applied in textbooks. They present the design and enactment of a school chemistry experiment, immediately followed by descriptions of phenomena and full explanations of them (Levi-Nahum, Mamlok-Naaman, Hofstein, & Taber, 2010).

In conclusion, teachers and textbooks do not always adequately take into account students' alternative conceptions. Moreover, this approach neglects the opportunity to evoke cognitive conflicts among students and to discuss them for changing their conceptions towards a better understanding.

The teacher/textbook factor: Using misleading verbal and visual models. Sometimes, teachers and textbooks are also not always very careful in using language and presenting pictures that are clear for students (Eilks, 2003; Eilks, Witteck, & Pietzner, 2012). They often use expressions and drawings that are common among chemistry experts ('you know what I mean') but their use is not always very adequate to students who are beginners in the field. One examples is given in Figure 2.

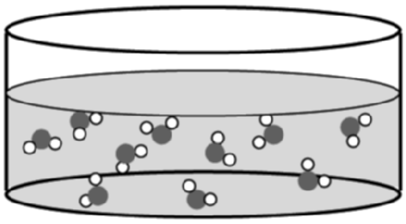


Figure 2. A hybrid picture: Molecules floating in a liquid

This is a problem of *hybrid language* and *hybrid pictures.* Firstly, hybrid language: An expression as 'water molecules consist of the elements hydrogen and oxygen' is unclear because it consists of a hybrid mix of a submicro meaning (molecules) and a macro meaning (element). In other expressions such as 'the substance of water contains atoms of hydrogen and oxygen' the term 'contains' suggests that these atoms are embedded in the substance. This will enhance students' alternative conception that the space between particles is not empty (see the former section). Secondly, hybrid pictures: A submicro picture of a liquid often looks like the one given in Figure 2. It suggests molecules that are floating in a liquid of which the surface is indicated by an oval line. This hybrid visual model corresponds with the latter verbal model mentioned above.

In conclusion, misleading verbal and visual models can contribute to foster students' difficulties in understanding multiple meanings and models.

The curriculum factor. All chemistry curricula for secondary schools address the four related domains. They also comprise models but many of them mainly focus on the content of models only. They do not pay much attention to the model concept itself, such as the nature and role of models and the function of modelling in chemistry. Moreover, many of them implicitly suggest that a particular model should be 'dropped' in the teaching of a topic. They rarely indicate the need to justify the implementation by clarifying why this model is appropriate and why another model has not been chosen.

In conclusion, many curricula mainly stimulate the teaching of models but ignore the importance of teaching about models and how to handle them. This omission contributes to evoke and enhance students' conceptual difficulties in understanding chemistry concepts.

THE PRACTICE OF CHEMISTRY TEACHING

Teaching multiple meanings

As indicated before, it is important be mindful of an adequate teaching of multiple meanings. This section presents suggestions for a basic teaching strategy, followed by a variant version of this strategy.

Basic strategy for teaching multiple meanings. You can start by selecting a chemical experiment that enables students to work with appropriate models for representing the reaction. Scale models can function as suitable starters. However, these models are often only available for students to represent molecular substances. Therefore, in the beginning, you should select an experiment that involves these substances, for instance the combustion of methane or other lower alkanes. In addition, you can select a teacher demonstration such as the reaction between hydrogen and oxygen or the hydrolysis of water.

After the selection of an experiment, you can apply a teaching strategy that includes the following four phases accompanying student activities (an example of the four-phase teaching strategy is given in Table 1):

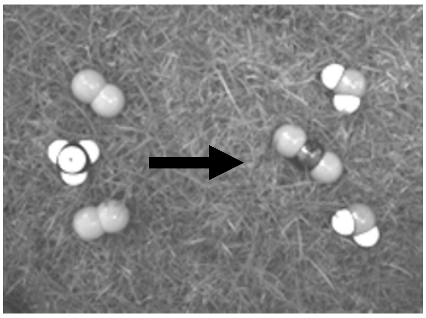
- *Macro phase.* Students do a hands-on experiment or you demonstrate an experiment. Then, students use the results for writing a macro reaction equation in words.
- *Submicro phase*. Students represent the reaction by using submicro models. They start with building material models (i.e. molecular scale models) followed by drawing visual models (i.e. 2D pictures of the scale models).
- *Symbolic phase.* Students transform their representations into symbolic models such as formulas, reaction equations, and so on.

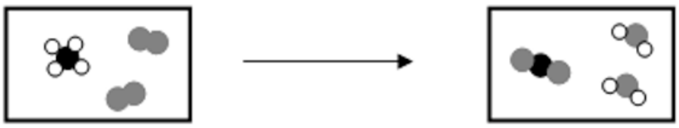
– *Process phase*. Students use the results from the three preceding phases for describing the chemical process in terms of breaking/forming of bonds, energy changes (i.e. indicating whether a reaction is exothermic or endothermic), and so on.

Table 1. Teaching multiple meanings: the case of combustion of methane

Macro phase.
Students examine the combustion of methane (main component of natural gas) by identifying the products as carbon dioxide and water. Then, they write a macro reaction equation in words, for instance:
methane (g) + oxygen(g) → carbon dioxide(g) + water (g).

Submicroscopic phase.
Students build molecular scale models and draw 2D pictures of them, for instance as given below.





Symbolic phase.
Students write a reaction equation in symbols, for instance:
$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$

Process phase.
Students indicate that the energy effect of the overall process of breaking and forming of bonds shows an exothermic reaction.

The classroom discussion in each phase can be guided by a specific leading question (see Table 2). At the beginning of each phase it is important that the teacher encourages students to become involved in the phase by explaining its value to them. This implies, for instance, that you clarify the reasons of using explanations in terms of particles at the beginning of the second phase, and, the profits of using symbols as shortened pieces of information (like the shortened expressions in sms-messages) at the beginning of the third phase. In each phase, you can ask students to work in small groups and to report their results in a plenary class discussion. At the end of each phase, it is important that you guide the class discussion and give feed-back on the outcomes from a scientific context.

Table 2. Leading discussion questions in the basic teaching approach

1. What do you see, smell, hear, feel? (macro)
2. What particles take part in the chemical process? (submicro)
3. What formulas/equations do represent this process? (symbolic)
4. What happens in terms of bonds, energy, etc.? (process)

Variant version of the basic strategy. Learning to understanding the four-domains relationship requires a lot of time and exercises. For that reason, it is important that the teacher builds up each phase of the procedure carefully and apply the whole procedure for a range of reaction types. However, some types require an adaptation of the basic teaching strategy. This can be illustrated by looking at the category of precipitation reactions between salts in solution.

Firstly, in the submicro phase, you have to skip the building of scale models as the first step of model formation. Building an ionic lattice from scale models of relevant ions is hardly possible at schools. More useful model building can be the drawing of pictures of ions forming an ionic lattice or computer visualisation (see Chapter 8). Role-playing by students can also be useful (see Chapter 7). In this play, each student represents a positive or negative ion and has a label with the indication (aq) on the arm. Through moving they can form a regular structured ensemble (with loss of the label).

Secondly, in the symbolic phase, it is important to pay extra attention to reaction equations, especially the writing of formula-units of salts. To avoid students' alternative conception that salts do not consist of ions because of the absence of charge in the formulas, it is better to put these charges in the formulas. For instance, in the beginning of teaching precipitation reactions, you can better write the precipitation reaction for silver chloride as $Ag^+(aq) + Cl^-(aq) \rightarrow Ag^+Cl^-(s)$. When students are more familiar with writing salt formulas you can replace $Ag^+Cl^-(s)$ by the simple AgCl(s) notation.

Finally, representations of precipitation reactions often provide a quite large collection of reacting ions and non-reacting 'spectator' ions and accompanying symbols. This overload of information can be confusing for students, especially when they try to connect the macro phase of the procedure with the other phases. You can support students to learn how to get a clear-structured overview by asking them to design concept maps (see Chapter 7). These maps show how concepts or processes are related by a web of nodes (concept or process labels) and links (relation terms). An example of a concept map including macro and symbolic meanings of a precipitation reaction is given in Figure 3. The use of concept maps implies an extension of the basic teaching approach.

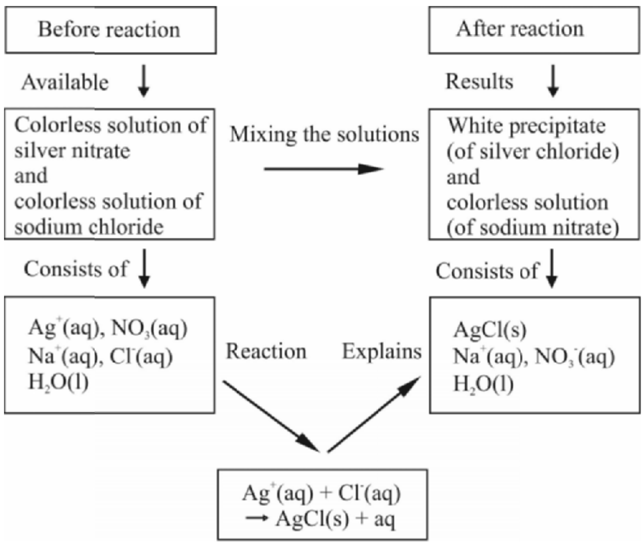


Figure 3. Concept map for a precipitation reaction including macro and symbolic meanings

Use of the Internet for teaching multiple meanings. You can use dynamic multimedia tools from internet that could support teaching and learning the four-domain relationship for a variety of topics. For each topic you can prepare student worksheets for fostering learning. Some relevant sites are given below (see Chapter 8).

- www2.oakland.edu/users/russell shows several real experiments, for instance the forming of some molecular and ionic compounds. The phenomena are represented by submicro-scale animations and particle models. Graphs of physical properties are also given.
- www.youtube.com/watch?v=tE4668aarck&feature=related presents examples of five major classes of chemical reactions: synthesis, decomposition, single displacement reaction, double displacement reaction, and combustion. Each reaction is presented by showing dynamic space-filling models of molecules of the reactants and the products and the accompanying reaction equation. In this way, meanings in the submicro and symbolic domains are related.
- www.youtube.com/watch?v=EBfGcTAJF4o&feature=related demonstrates the phenomenon of dissolving salt in water and relates this process to the submicro domain by using dynamic space-filling models.
- www.youtube.com/watch?v=yjge1WdCFPs&feature=related presents examples of the forming of ionic bonds and covalent bonds. Each bonding type is introduced by a laboratory demonstration. The ionic bonding is related to the

reaction between sodium and chlorine and the covalent bonding to the reaction between hydrogen and oxygen. A submicro explanation of the forming of the bonds is also given. In this way, meanings in the macro domain and submicro domain are related.

Teaching about models

As indicated before, it is not only important to teach particular models but also to teach about the nature and function of models. The latter is elaborated by offering four specific teaching suggestions. A summary is given in Table 3.

Firstly, you can focus students' attention on the core nature of models by indicating similarities and differences between model and target explicitly (see below) and asking students to carry out modelling tasks (see the next sub-section). This teaching approach can support students to change their conception of models as exact small-scale copies of reality.

Secondly, when talking about the relationship between a model and a target it is important that you indicate the existence of similarities and differences between model and target. For instance, a common ball-and-stick model of a water molecule indicates the number of constituent atoms, the kind of atoms (white-coloured hydrogen balls and a red-coloured oxygen ball) and the spatial structure (109° between the hydrogen atoms). However, some important differences are the indicated size of the atoms, the bonding between the atoms (no sticks) and the colour (an individual atom does not possess a visible colour). Another example regards the ball-and-stick models of the ionic lattice of ionic compounds. Many students compare these models with ball-and-stick models of molecular compounds, and, for that reason, they think that covalent bonds are also present in ionic compounds. However, the sticks in models of molecules represent high electron density between the atoms, while the sticks in lattice models are only needed to hold the balls together physically. The electron density between the ions drops towards zero in the space between the ions. The balls in ionic lattice models are often similar in size. However, this ignores real differences between ions. In sum, when using stick-and-balls models, it is important that you address differences between this type of model and the target in terms of size of balls and meaning of sticks in order to avoid students' alternative conceptions.

Table 3. Strategy for teaching about models

1. Indicate that models are not exact small-scale copies of reality.
2. Address similarities and differences between model and target.
3. Point out that model choice determines the meaning of a concept.
4. Review the power and limitations of models.

Thirdly, you can point out that the meaning of a concept depends on the model that is chosen. For instance, NH_3 molecules can be considered as a base and H_2O molecules as an acid or a base (Brønsted model) or not at all (Arrhenius model). Another example regards the reaction between sulphuric acid and water. This reaction can be classified as an acid-base reaction according to the Brønsted model but not according to the Arrhenius model because of the absence of a substance that produces OH^- ions. You can also point out that chemists' choice of a particular model is often guided by their research questions that they want to answer.

Fourthly, it is also important to indicate the power and limitations of any model: some models are more appropriate than others for describing, explaining or predicting particular chemical phenomena. For instance, you can show a space-filling model and a ball-and-stick model of a particular molecule and point out that both scale models are representations of the same molecule. You can also clarify that each type of model has specific profits and disadvantages. For instance, the stick-and-ball model offers a more clear describing picture than the space-filling model about the spatial geometry of atoms and the bond orders necessary for identifying functional groups, but the sticks themselves and their lengths are misleading. A lot of information about 3D molecule structures in different representation modes is given on the site: www.wellesley.edu/Chemistry/Flick/molecules/newlist.html (see Chapter 8).

Teaching with analogical models

You can clarify difficult abstract concepts or processes through presenting analogical models. These models (hereinafter shortened to analogies) are designed by mapping similar features from a scientific concept or process (the target) onto a real world object or event (the analog). Examples of analogies are: 'the mechanism of a chemical reaction is like assembling a racing car in a factory, because both processes proceed step by step' and 'forming a chemical bond is like the snapping together of two strong magnets, because in both cases there is output of (sound) energy.'

Strategy for using analogies. Teaching with analogies is not as simple as it may look. For that reason, the following issues need your attention.

Firstly, analogies are never based on a full one-to-one fit between target and analog, so, there are always shared and unshared features. For instance, collisions between balls on a billiard or pool table can represent inter-atom collisions, but the air between the balls does not represent the vacuum between atoms.

Secondly, analogies can only be effective when students are familiar with the analogs and perceive them as interesting. For instance, an analogy including the analog of assembling a racing car (see the analogy above) could be attractive for boys only; girls could be more interested when the analogy refers to the areas of cosmetics or clothes.

Thirdly, analogies can also be designed by students. They use them, for instance, when they explain an abstract concept to a peer student with conceptual difficulties.

These three points are incorporated in the stepwise strategy for teaching with analogies given in Table 4.

Table 4. Strategy for using analogies (Harrison & Treagust, 2006)

Before teaching: be creative * Select a new conception that could be difficult or uninteresting. * Look for an analogy that could be interesting and easy to understand.
During teaching: be constructive * Present the analogy. * Discuss similarities and differences between analog and target. * Stimulate students to suggest alternative analogies and discuss them.
After teaching: be critical * Reflect on introduction and students' understanding of the analogy. * Consider revisions of the lesson for the next time.

Teaching about modelling

As indicated before, modelling is an important activity in chemistry. This comprises the designing, the revising and the replacing of models by chemists. Teaching about modelling can help students to accept that models are human cognitive constructions and not exact small-scale copies of reality itself. Two specific teaching suggestions are elaborated.

Address modelling through students' tasks. You can teach about modelling by asking students to carry out modelling activities by themselves, and, after their activities, you can point out the steps of the process of modelling explicitly. Some simple examples are given below.

– *3D structures and properties of substances.* You can ask students to build scale models of molecules of some lower alkanes and alcohols by offering them a box with scale models of the atoms of carbon, hydrogen and oxygen. In the building process, students will be confronted with the need to consider the revision or replacement of drafts of models because of the isomer option. Students can use the final version of the models to suggest how these structures relate to differences in properties of the substances, for instance, their boiling points and solubility in water. You can also ask students to compare the 3D structures of the isomers of C_4H_{10} for predicting which of them might have the highest boiling point (regarding C_4H_{10} it is butane; students may explain that this could be because butane molecules have a more linear structure so they can be more close to each other compared with the branched molecules of 2-methyl propane).

– *3D structures and structural formulas.* You can ask students to build molecular scale models of some inorganic substances (no salts and metals), for instance hydrogen chloride, water and ammonia. Because of this task, you can offer students a box with a stock of different coloured paperclips or a box with polystyrene balls and toothpicks. When using these clips or balls and picks, it is possible to discuss the problematic relationship that can exist between molecular formulas and structural formulas. For instance, using paperclips or balls and toothpicks makes it is possible to represent a water molecule as H – O – H but also as H – H – O, and an ammonia molecule as N – H – H – H or H – N – H – H, and so on. Making a choice for the right structural formula can be based on a discussion on the bonding in the molecule. Because of this discussion students have to carry out the usual modelling activities of revision or replacement of their drafts of models.
– *3D structures and chemical reactions.* You can ask students to build molecular scale models of the reactants and products of a chemical reaction, for instance the combustion of alkanes, and ask students to examine the process of breaking and forming of bonds. You can also ask them to use the molecular models for examining quantitative aspects (stoichiometry) of these combustion reactions.

Address modelling through considering models in a historical context. You can also teach about modelling by addressing the historical development of the model that you introduce (see Chapter 1), especially by pointing out that the revision or replacement of the model is mainly triggered by results of empirical experiments. Some teaching suggestions are given below.

– *Atomic models.* You can address the historical development of the atom concept from Democritus to Bohr. You can also focus on a piece of this history only. For example, you can indicate that Thomson proposed in the 1890s the concept of negative particles (electron) based on his cathode rays experiments. He used this concept for revising Dalton's atomic model (1808) by the idea that an atom consists of electrons embedded in a sphere of uniform positive charge ('currant bun' model). Some years later (1911), Rutherford replaced Thomson's model by describing the atom as having a central positive nucleus and negative electrons at the outer site of a ball. He also suggested that the atom mostly consists of empty space. Rutherford based his model on the results of a gold foil experiment. A simulation of his very famous experiment can be found on: www.mhhe.com/physsci/chemistry/essentialchemistry/flash/ruther14.swf. This simulation clearly separates between the experiment (macro) and the accompanying explanation (submicro). This example can help students to realize how scientists revise or replace existing models by interpreting new experimental results.
– *Combustion models.* You can inform students that in the 17th and early 18th century all flammable substances were supposed to contain a substance called Phlogiston, which was released when the substance burned (see Chapter 1). This

model of combustion was replaced in the 1770s by Lavoisier who showed by experiments that Phlogiston does not exist. He found that a gas, which he named oxygen, was taken up to form one or more combustion products.

– *Oxidation-reduction models.* You can point out that in the 1770s Lavoisier coined the term oxidation to any reaction of a substance with oxygen and used the term reduction for the removal of oxygen from the products. After the introduction of the electron, Lewis used this concept for grounding a more general model in 1916 by defining a redox reaction as a combination of two half reactions including transfer of electrons. This model also regards reactions without any involvement of oxygen. Later on, Latimer introduced the term oxidation number as a completely formal notion, describing a redox reaction as a reaction connected with changes of oxidation numbers.
– *Acid-base models.* You can indicate that in the 17th century Boyle described acids as substances with a sour taste and bases ('alkalis') as substances that have the ability to neutralise them. At the end of the 19th century Arrhenius used his work on electrolytic dissociation to revise this model by defining acids and bases as substances that produce H^+ ions (acids) or OH^- ions (bases) in an aqueous solution. In the 1920s a more general model was introduced by Brønsted (and also by Lowry) who defined acids and bases as particles that donate protons (acids) or accept protons (bases). Their model exceeds the acid-base model to solvents other than water such as ammonia. In the same period of time this model was extended by Lewis who defined acids as electron pair acceptors and bases as electron pair donors. This extension also comprises of reactions that do not involve ions.

Taking students' (alternative) conceptions into account

Strategy for taking students' (alternative) conceptions into account. You can take students' (alternative) conceptions into account by offering space to students for expressing their own ideas about a particular concept or process, followed by classroom negotiations about relevant multiple meaning and models. For instance, you can encourage students to speculate about possible explanations of chemical phenomena and to discuss why some explanations are more preferable than other ones. The sharing and negotiating of explanations can be stimulated by asking students to work in small groups by applying the following teaching strategy.

– *Initial (alternative) conceptions*. The participants of each group design explanations of observed chemical phenomena, for instance regarding a series of precipitation reactions. They discuss them within the group till consensus. Activity sheets can be helpful to make the internal communication more clear and smooth.
– *Reporting the (alternative) conceptions*. The group results are presented to the other groups, for instance by presenting concept maps about the precipitation reactions including macro and symbolic meanings (like the one in Figure 3). After each presentation there is time for questions, requests for further clarifications, and other comments.

– *Common class (alternative) conceptions.* The class discusses the group results aiming at looking for consensus about the most plausible explanations of the observed phenomena, for instance the colour of precipitates.
– *Taking (alternative) conception into account*. After this group work, you can take the common students' explanation into account when you address the scientific explanations of the phenomena for a final discussion with the class.

Use of clear verbal and visual models. You can prevent evoking students' (alternative) conceptions by using clear language and pictures. When preparing lessons, you can analyze relevant textbook chapters and look for expressions and pictures that could be misleading for students. In the lessons, you can focus students' attention to them and explain or revise them to foster understanding.

In case of *hybrid expressions*, you can replace them by more consistent expressions. For instance, the expression 'water contains the elements hydrogen and oxygen' can be replaced by the macro expression 'the compound of water can be decomposed into the elements hydrogen and oxygen' or the submicroscopic expression 'water molecules consist of atoms of hydrogen and oxygen.'

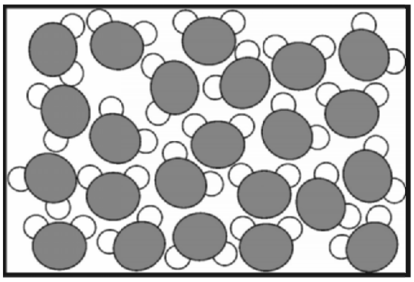


Figure 4. Submicroscopic model of molecules of a liquid

In case of *hybrid pictures*, you can replace them by less misleading ones. For instance, you can replace the usual picture of molecules of a liquid such as the one in Figure 2 by a diagram as given in Figure 4. In this picture there is no misleading mix of macro and submicroscopic information. Any indication of a surface is lacking just as floating molecules in a liquid. It is a real submicroscopic diagram. Moreover, by drawing the molecules as close as possible to each other, the diagram illustrates that liquids have a low compressibility (important for hydraulic purposes), especially compared to gases.

Teaching with cognitive conflicts

As indicated before, many students are not very likely to look for and to accept new conceptions when these conceptions block their alternative conceptions, especially when these have roots in everyday life. You can motivate students for conceptual change by creating cognitive conflicts. As a starting point, you can present a phenomenon that is familiar for students or that is new for them.

Use familiar phenomena for evoking cognitive conflicts. Familiar phenomena can confront students with their alternative conceptions. For example, for teaching the relation between particle and substance, you can show a white sugar cube from the kitchen and point out that sugar molecules consist of carbon atoms, oxygen atoms and hydrogen atoms. Students will have the alternative conception that sugar molecules are white, carbon atoms are black, and atoms of oxygen and hydrogen are colourless. You can evoke a cognitive conflict by indicating that the sugar has no black spots on it or in it and is not gaseous. A subsequent classroom discussion can contribute to change students' alternative conceptions of features of single particles.

Use new phenomena for evoking cognitive conflicts. New phenomena can also confront students with their alternative conceptions. Examples including experiments are given below.

A surprising conflict for students: *Solutions of 1M HCl and 1M acetic acid have a different pH*. When introducing weak acids, you carry out an experiment reported by Baddock and Bucat (2008). You prepare hydrochloric acid solutions with concentrations 1M, 0.1M, 0.01M, and 0.001M in front of the class by successive dilutions from the 1M solution, and samples of each are put into Petri dishes. Then, you add methyl violet indicator to each solution, producing the colours yellow, green, blue, and purple, respectively. Finally, you add a 1M acetic acid solution to a fifth Petri dish and ask students to predict what colour the methyl violet indicator would go when added. The indicator is added and observed to go blue. Many students will not expect this colour. You can create a cognitive conflict by asking for an explanation. Students will experience dissatisfaction with their existing knowledge that does not provide a plausible explanation. You can present and discuss a more plausible clarification by addressing properties of weak acids in terms of a particle model.

Another surprising conflict for students: *Bubbles at a copper bar in a solution of 1M sulfuric acid*. When introducing galvanic cells, for instance the Daniell voltaic cell, students carry out an experiment reported by Baral, Fernandez, and Otero (1992). Students put a zinc bar in a beaker with 1M sulfuric acid solution (producing bubbles), and a copper bar in another beaker with 1M sulphuric acid solution (no bubbles). The results of both experiments will be well-known for students. Then, they connect the bars with a metal wire and place the connected bars in a third beaker with the solution. Soon, bubbles can be observed as indicated in Figure 5. Many students will not expect this phenomenon. You can create a cognitive conflict by asking for an explanation. You can present and discuss a more plausible clarification by addressing the relationship between electrolyte, electrode, and electrode reaction.

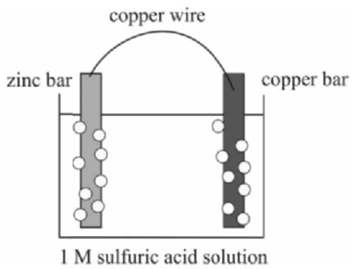


Figure 5. Schematic representation of an experiment evoking a cognitive conflict

A last surprising conflict for students: *Chemical reactions are reversible.* When introducing the reversibility of chemical reactions, students carry out an experiment reported by Van Driel, De Vos, Verloop, and Dekkers (1998). This experiment concerns the system of cobalt (II) tetrachloro and cobalt (II) hexahydrate complexes in 2-propanol. You prepare this system by adding 1 g of cobalt(II) chloride hexahydrate (pink) to 25 ml 2-propanol and mixing for about 25 minutes at room temperature. The solution is deep blue (excess of the chloro complex) but after adding some water it becomes pink (excess of the hydrate complex). Students get 3 ml of a blue coloured solution in their test tube. When they add some water, the colour changes into pink whereas the addition of some ml of a solution of calcium chloride in 2-propanol turns the pink colour into blue, and, finally, adding another amount of water changes this colour into pink again. Many students will not expect these phenomena, because, till then, they are familiar with reactions that take place in one direction only. You can create a cognitive conflict by asking for an explanation. Students will experience dissatisfaction with their existing knowledge that does not provide a plausible explanation. You can present and discuss a more plausible clarification by addressing the existence of reversible chemical reactions. You can also describe the present reversible reaction in terms of two simple opposite word equations.

Strategy for using cognitive conflicts. Teaching with cognitive conflicts is not as simple as it may look. For that reason, the following issues need your attention.

Firstly, cognitive conflicts require new conceptions that are not only intelligible but also more plausible and fruitful than the old ones. Secondly, cognitive conflicts can only be effective when students perceive them as a challenge for examining their existing conceptions. Thirdly, cognitive conflicts can lead to conceptual change, but it is also possible that the new conceptions exist beside the old ones. For instance, students are able to use a new conception in the chemistry classroom but use the old conception at home. So, the use of conceptions is context-related.

These three points are incorporated in a stepwise strategy for teaching with cognitive conflicts that is given in Table 5.

Table 5. Strategy for using cognitive conflicts

Before teaching: be creative
* Select a new conception that could be in contradiction with existing conceptions.
* Look for a cognitive conflict that could be challenging for students.

During teaching: be constructive
* Confront students with a conflicting new conception.
* Address the question whether this conception is intelligible, more plausible and fruitful.
* Discuss the context-dependent value of new and old conceptions.

After teaching: be critical
* Reflect on introduction and students' understanding of the cognitive conflict.
* Consider revisions of the lesson for the next time.

Tools for identifying students' (alternative) conceptions

Useful tools for identifying students' (alternative) conceptions are tasks for analysing and designing submicro diagrams and concept maps. Examples of these tools are given below.

Students' tasks for analysing submicro diagrams.

– *Analysing diagrams of a mixture.* Students look at some submicro diagrams showing different mixtures in the gaseous state, for instance the diagrams in Figure 6. They have to select the diagram that represents a mixture of two compounds. They also have to explain their answer.

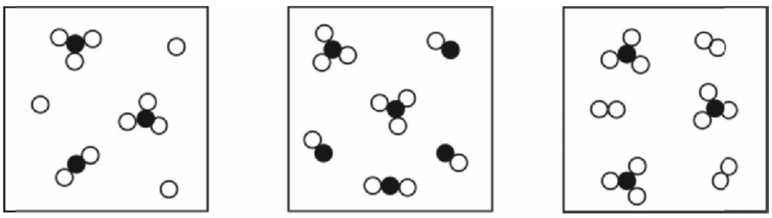


Figure 6. Submicroscopic diagrams representing mixtures of gaseous substances

– *Analysing diagrams of a chemical reaction.* Students look at two submicro diagrams showing a chemical reaction between X and Y. One diagram represents the reactants and the other one the products. Several possible reaction equations are also given. Students have to select the equation that correctly links the diagrams. They also have to explain their answer.
– Analysing a diagram of a vapour. See the task given in Table 6.

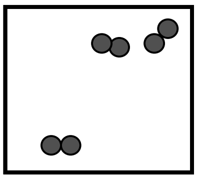
Table 6. Task for analysing a diagram of a vapour

Students read the classroom episode below. They have to write their comments in terms of the colours of the particles and the disposition of the particles. Thereafter, they have to explain their answer.

- -

A classroom episode:

The teacher places a crystal of iodine in a closed warm tube. After a while, there is a violet colour throughout the tube. Some of the solid iodine has changed into vapour. Students draw a submicroscopic diagram to show the arrangement of the iodine molecules in the solid and the vapour. A student, Sam, drew this picture as follows:



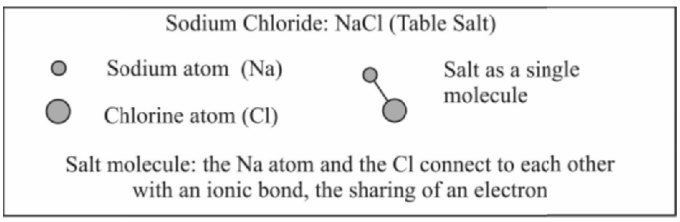
– Analysing a partly incorrect diagram and explanatory text. See Table 7.

Table 7. Task for analysing a diagram of NaCl and explanatory text

Students look at the diagram and text below. They have to write down the parts of the diagram and explanatory text that they believe to be scientifically incorrect. Subsequently, they have to change the drawing and the text to correct them.

- -

(www.sciencekidsathome.com/science_topics/what_are_crystals.html)



– Students' tasks for designing submicro diagrams.
  - *Designing diagrams of formulas and chemical reactions.* Students have to design submicro diagrams of given formulas such as $2HCl$, $3H_2O$ and $4NH_3$. Students also have to draw submicro diagrams of a particular reaction based on a given reaction equation (in words or symbols). They have to explain their diagrams by discussing why they drew them as they did.

  - *Designing diagrams of chemical bonding.* Students have to design submicro diagrams of given substances, for instance chlorine and methane, which also show the relevant chemical bonding. They have to explain their diagrams by discussing why they drew them as they did.
- Students' tasks for analysing and designing concept maps (see Chapter 7).
  - *Analysing concept maps.* Students read concept maps and have to explain their interpretations. They also have to indicate difficulties in understanding particular terms or linkages. As an alternative task, students read incomplete concept maps, for instance, a map lacking some relation terms. They have to complete the maps by writing terms or short sentences at each link and to explain the results.
  - *Designing concept maps*. Students have to design concept maps for particular topics, for instance a map that describes properties of solutions of an oxidizing agent and a reducing agent and the accompanying oxidation-reduction reaction indicated in terms of particles and symbols. They also have to explain their maps.

Five provocative pieces as food for further thinking

This section deals with some provocative issues for you that can be used for further thought. You can also discuss these issues with peers in the context of pre-service and in-service workshops.

Molecular and atomic models. These models can be introduced early or later on in the teaching of chemistry. Usually the teaching of reacting substances is followed by the teaching of particles as explanatory models. For instance, the burning of substances is often introduced in an early stage, but students experience a lot of difficulties in recognising and understanding this event as a chemical reaction. They begin to accept the idea of substances changing into other substances only after the introduction of the particle model. However, a premature introduction to particles can generate many difficulties at the submicro level as reported before (see sub-section on difficulties with macro–submicro relationship). You can reflect upon when is the best moment to introduce molecular and atomic models (Johnson, 2002).

Chemical bonding. When this topic is introduced, the teaching of covalent bonding is often followed by the teaching of ionic bonding. This order of introduction can stimulate students to reason that ionic substances consist of discrete molecules made from uni-directional bonded ion-pairs. In other words, there are ionic molecules as there are also covalent molecules (see sub-section on difficulties with the process domain). To prevent this misunderstanding, you can think about the possibility of changing the usual order of introducing chemical bond models (Taber, 2001).

Acid-base models. As indicated before, students encounter difficulties in making a clear distinction between the Arrhenius model about acids and bases as substances and the Brønsted model about acids and bases as particles (see subsection on difficulties with models). They mix parts of each model which leads to the use of a hybrid acid-base model. Because of these difficulties and the broader application range of the Brønsted model, you can reflect on the possibility to teach the Brønsted model only and, afterwards, to present the Arrhenius model as an interesting historical model (Hawkes, 1992).

Oxidation number. As indicated before, students have difficulties in understanding the meaning of oxidation number (see sub-section on troubles with models). Because of these difficulties, this model is deleted from some school chemistry curricula. But students may use a book of tables, in class and at examinations instead, including a table with standard electrode potentials related to a broad range of half reactions. You can reflect on the benefits and disadvantages of this way of teaching redox reactions (De Jong & Treagust, 2002).

Macro-submicro relationship. As indicated before, students have a lot of alternative conceptions, which can hinder their conception of relations between the macro and submicro domains (see the sub-section on this issue). Because of their difficulties, you can think about the possibility to insert a domain in between: the meso domain. This domain mainly deals with structures of materials and their properties. Meanings and models in the meso domain can function as links between macro meanings and models, and submicro meanings and models (Meijer, Bulte, & Pilot, 2009).

SUMMARY: KEY SENTENCES

- Students encounter a lot of difficulties in understanding the relations between the four important domains of meaning in chemistry: the macro, submicro, symbolic and process domain. A step-wise strategy for teaching multiple meanings contributes to reinforce students' understanding of the relations between phenomena with the submicro and symbolic representation.
- The students have a lot of difficulties in understanding the nature and function of scientific models and modelling. It is not the teaching *of* models and modelling but the teaching *about* models and modelling that contributes to supports students' understanding of the nature and function of models and modelling.
- Many difficulties can be explained by the student factor (e.g. mismatch between everyday conceptions and scientific conceptions), the teacher/textbook factor (e.g. ignoring students' alternative conceptions), and the curriculum factor (e.g. hardly any focus on the model concept).

– Teachers' expertise in chemistry can be one source of students' conceptual difficulties. Awareness of this impact of this source is a first step to prevent evoking students' alternative conceptions of multiple meanings and models. Omitting the use of hybrid language and pictures in teaching contributes to students' development of a clear understanding of the relation between the macro, submicroscopic and symbolic domain.
– Students should be encouraged to speculate about possible explanations of phenomena and to discuss and negotiate the explanatory power with peers in small groups. A step-wise strategy for teaching with cognitive conflicts is important for students to accept new conceptions that do not match their everyday conceptions. A step-wise strategy for teaching with analogical models is fruitful for clarifying many difficult abstract concepts and processes.

ASK YOURSELF

1. Design a concept map that describes properties of solutions of a particular oxidizing agent and a particular reducing agent and the accompanying oxidation-reduction reaction indicated in terms of symbols (see also Figure 3).
2. Search for misleading verbal expressions and pictures in chapters of your school chemistry textbook that deal with phenomena and related models. Improve these expressions and pictures.
3. Outline a lesson in which you introduce the idea of scientific models for the first time (see also Table 3).
4. Prepare a teaching episode that includes the possibility of evoking a cognitive conflict that can support your students to understand a new chemistry concept (see also Table 5).
5. Describe your opinion about the value of the five provocative issues presented in the sub-section before the 'key sentences' section (molecular and atomic models, chemical bonding, acid-base models, oxidation number, macro-submicroscopic relationship).

HINTS FOR FURTHER READING

Talanquer, V. (2011). Macro, submicro, and symbolic: The many faces of the chemistry "triplet." *International Journal of Science Education*, *33*, 179-195. The article proposes a general structure of our chemistry knowledge. This structure may be useful in the analysis and reflection of teaching practices centred on relating the macro, submicro, and symbolic domains of meaning.

Gilbert, J. K., & Treagust, D. (eds.) (2009). *Multiple representations in chemical education*. Dordrecht: Springer. The book addresses several aspects of the triplet relationship between the macro, the submicro, and the symbolic domain of meaning. It discusses conceptual difficulties that students encounter and presents cases of teaching approaches, for instance, regarding the introduction of inorganic qualitative analysis and the use of multimedia tools.

Gilbert, J. K., De Jong, O., Justi, R., Treagust, D. F., & Van Driel, J. H. (eds.) (2002). *Chemical education: Towards research-based practice*. Dordrecht: Kluwer. The book elaborates the four domains of learning difficulties and related teaching strategies for a range of curriculum topics: particulate nature of matter, bonding, chemical equilibrium, chemical kinetics, electrochemistry, chemical energetic, and thermodynamics.

Oversby, J. (2000). Models in explanations of chemistry: the case of acidity. In J. K. Gilbert, & C. J. Boulter (eds.) *Developing models in science education* (pp. 227-251). Dordrecht: Kluwer. This chapter focuses on the development of modelling, using the context of acidity for exemplification. The explanatory power of different models is one of the points of discussion.

Taber, K. S. (2002). *Chemical misconceptions – prevention, diagnosis and cure* (2 Vols.). London: Royal Society of Chemistry. The first volume of this book addresses a number of theoretical background notes about chemistry students' alternative conceptions that have been uncovered by research. The second volume offers a number of ideas about a variety of teaching approaches for lower secondary school level.

Blonder, R., Joselevich, E., & Cohen, S. R. (2010). Atomic Force Microscopy: Opening the teaching laboratory to the nanoworld. *Journal of Chemical Education*, *87*, 1290-1293. The article provides background information about the nanotechnology of Atomic Force Microscopy (AFM) – see the internet site below - from an educational point of view.

RESOURCES FROM THE INTERNET

CARD: *www.card.unp.ac.za*. This site gives information about students' conceptual and reasoning difficulties (CARD). It contains many references about a range of topics in chemistry education such as the particle nature of matter, chemical bonding, acids and bases, chemical equilibrium, electrochemistry, stoichiometry, and thermodynamics.

Atomic Force Microscopy: *www.doitpomps.ac.uk/tlplib/afm/index.php*. The AFM site offers visual models of molecules and atoms on surfaces of substances at nano level. Students can simultaneously observe both the scanning of a substance's surface (as recorded by a video optic zoom) and the surface image being recorded at nano level.

RSC: *www.chemsoc.org/networks/learnnet/miscon2.htm*. This resource from RSC provides a number of worksheets that can be downloaded and customised for use in lower secondary chemistry classrooms. They are related to Taber's book, Vol. 2 (see Hints for Further Reading).

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SILVIJA MARKIC, JOANNE BROGGY & PETER CHILDS

5. HOW TO DEAL WITH LINGUISTIC ISSUES IN CHEMISTRY CLASSES

Language is one of the central mediators of any learning process. But, understanding the specific language of a domain is also the entrance of a learner to be enculturated to the specific field of interest. This makes the learning of language an objective of its own. The chapter will discuss the role of linguistic issues for learning in general, and of chemistry education in particular from both of the above mentioned perspectives; the teacher and the learner. The chapter will deal with how to become able to communicate in and about chemistry by learning the special language of chemistry with its technical terms, formulae, or modes of argumentation. But teaching chemistry is also often confronted with problems in students' general abilities in talk, read and write. Finally, the chapter will therefore shed light on the issue how to deal with growing linguistic heterogeneity in chemistry classes in many countries. In the practical part of the chapter examples will be presented on how to deal with linguistic issues in the chemistry classroom.

THEORETICAL BASIS

Grade 5, age 10-11, chemistry, topic "Water in our surrounding": The class was very heterogeneous in any kind, e.g. age, linguistic skills, knowledge, migration background … The language teacher told us that the class is very heterogeneous and almost all of the students have difficulties writing properly and expressing their knowledge and thoughts. The students were doing an experiment about different properties of water. The teacher gave them a work sheet with an instruction. However, the work sheet was much different than the sheets that teachers usually use. On the new work sheet there were more pictures, sentences were much shorter, and the experiment was a sequence of drawings. The students were asked to write down their observations. After some time, one of the boys stood up and went to the teacher desk. The teacher was prepared that the student would ask for assistance; he already prepared some cards for help. Finally, the student came to the teacher with his work sheet in hand and pointed to the sheet by saying proudly: "Look, this sentence I wrote by myself!"
From a report of a student teacher from the University of Bremen after a chemistry teaching internship.

I. Eilks and A. Hofstein (eds.), Teaching Chemistry – A Studybook, 127–152.

Why focus on language in chemistry education

Language is a tool that we all use in our everyday life. We use language for communication purposes and to express our thinking, desires, ideas, and feelings. We use language to capture and express any kind of information or thought. This also is the case in any teaching and learning activity. Language is central for any learning process where lessons take place most of the time on a linguistic level. Almost all of the teaching and learning activities are mediated by language, either oral or written.

In science education, language has been traditionally understood as a simple vehicle through which to transfer information (Fang, 2006; Ford & Peat, 1988). It was considered as having rather a passive role with low influence on the learning process as such. However, in the last decades the consideration of the role of language for learning chemistry has changed dramatically. Today, language is more and more considered to be one of the central issues that fosters or hinders learning in general, and in the chemistry classroom in particular. Chemistry education became increasingly aware that linguistic abilities and chemistry learning do interact. For example, Lee and Fradd (1998) and Lee (2005) showed that a lack of linguistic skills and unfamiliarity of asking questions, investigating, and reporting results using science language can de-motivate students towards their science lessons. However, it was shown that inquiry-based learning (see Chapter 6) supports students' language development.

Language is a mediator in any learning process in general and in chemistry education in particular (Grabe & Stoller, 1997). The promotion of language competencies is one of the objectives of chemistry teaching. It is one of the central aims of chemistry education, for students to learn the language of chemistry with its technical terms, formulae, and patterns of argumentation. The more difficulties that students have in understanding the language of chemistry, the more difficulties they will have in using teaching and learning materials in their future chemistry education. Learning the language of chemistry is a necessary prerequisite to further learning and understanding chemistry, but also to allow accessing the community of chemists with their debates, journals or conferences, or to participate in societal debate on socio-scientific issues. This process of getting access to a community of research or practice by learning its language is termed by the Russian psychologist Vygotsky as 'enculturation' (Hodson & Hodson, 1998). While the students improve their scientific language, they require a shared understanding of the content (Brown & Ryoo, 2008). Raising their scientific language ability will help in developing their understanding and increase their "*ability to observe, to think logically, and to communicate effectively*" (DES, 1999).

Wellington and Osborne (2001) claim that knowing and understanding the language of science is an essential component of scientific literacy. It is essential that every student is able to comprehend and explain in clear language fundamental science concepts. There are several activities that take place in the classroom including reading, writing, and listening, to name a few, which include the use of science language and the students require a good understanding of language in order to learn. For example, during problem solving students read and write using scientific language: written language is used to read the text and spoken language is used to communicate the path taken from the initial state to the goal (Lemke, 1989).

But, there is also another justification. Since the 1990's, the achievement of *Scientific Literacy for All* has become a widely accepted goal for any formal science teaching at primary and secondary level (AAAS, 1993; NRC, 1996; see Chapters 1 and 2). In this approach, scientific literacy describes the competencies to be achieved by students, through science teaching, in being able to communicate about science and to participate in public debate about scientific, technological, social, and ecological topics. Phillips and Norris (1999) and Norris and Phillips (2003) refer to the ability to infer meaning from the text, and to use the information rationally during discourse or decision-making in science-related personal and social issues, as a main feature of scientific literacy. To reach this aim it is important that in science/chemistry lessons the language and pupils' linguistic competencies are emphasised.

The correct use of scientific language and the ability to understand scientific writing is an important part of scientific literacy in both of the above discussed meanings. One cannot be scientifically literate (i.e. being able to use, understand and explain the main ideas of science or to participate in societal debate about a science related issue, e.g. climate change) without understanding and being able to use language in a science-related context adequately. Therefore, one test of scientific literacy might be the ability to read and comprehend a science-related article in a newspaper (Bybee, 1997).

The lack of facility with language in science education may be one of the major factors hindering student learning in science but it is one factor that the teachers often ignore or take for granted. This low level of literacy in relation to science is also an important factor affecting scientific literacy – even after school education has finished. Try counting how many specialists or 'unusual' words there are in a single science article or in a practical task (Johnstone & Wham, 1982), and this problem gets worse as the level increases. Science textbooks and science articles in journals require a higher reading level than normal prose, e.g. novels. Read a chapter of a book in a subject you are not familiar with (economics or law) and see how significant an understanding of the language used is for your comprehension of the text. This is what students' experience, particular on lower secondary level, when they open a science textbook for the first time or when as citizens later on they are confronted with a science-based article in a daily newspaper.

In relation to the structuring of chemistry lessons, this means that the pedagogy should take account of the students' prior-competencies in the use of talking, reading, and writing in general, but also focus on learning the basic skills in the use of the language of chemistry. This chapter will focus on (a) the role of language for the learning in chemistry, (b) learning the language of chemistry, and (c) pedagogies of dealing with chemistry in classrooms covering problems which are related to students' language abilities and linguistic heterogeneity.

The role of language in the learning of chemistry

The dichotomy between language and chemistry (and science in general) is widely documented in the literature (Lee & Fradd, 1998; Lee, 2005). In schools we can see that not only students but also a majority of both language and chemistry/science teachers see language and chemistry/science lessons as independent of each other. However, newer studies showed that there is a close connection between language and science learning.

It is widely accepted, that students' knowledge, especially in the domain of chemistry is a key for successful problem solving. Further it is commonly agreed that students need different types of knowledge for learning and understanding, which include: conceptual, procedural, situational and strategic knowledge, and respective abilities (De Jong & Ferguson-Hessler, 1996). All learning processes in classroom can be understood as processes of exchange and mediation (Vygotsky, 1978). Information needs to be captured from written material, the teacher, or classmates. Ideas need to be expressed, exchanged, or debated. Action needs to be negotiated and finally agreed upon. All these processes of communication take place through the use of language, both in oral or written form. This means that a very strong link exists between the issues of information and knowledge and students' linguistic skills, in general and specifically with scientific language (Cassels & Johnstone, 1984).

It seems somewhat self-evident that if a student's language skills are poor, particularly in reading and writing, and if they have a limited word pool, then he/she will face a severe disadvantage in learning any new content, e.g. chemistry. This is clear if we think about how much reading and writing we do in a chemistry lesson: reading textbooks, worksheets, PowerPoint slides, tests, and writing laboratory reports, taking notes, answering homework questions, etc. The problems will be enhanced for someone whose first language is not the official language of the country she/he is living in and is thus being taught in a foreign language. These students learning in a second language may not understand even simple words or understand a whole sentence, question, or instruction, not to mention the new scientific terminology they encounter.

The basic theory behind considering the role of language for learning is constructivism. Constructivism is the most commonly embraced learning theory in modern education (Bodner, 1986). Constructivism means that knowledge cannot easily be transferred from one mind to another. Information captured – via language or graphical information – will not be stored in the mind of the learner unchanged. Constructivism says that knowledge is constructed in the mind of the learner based on experiences, attitudes, prior-knowledge, and cognitive abilities, i.e. prior knowledge acts as a filter for new learning (see Chapter 4).

Constructivism understands learning as an active process by the learner in capturing information and treating it with concern to their cognitive abilities. The learners make connections to knowledge they already possess, and assimilate the knowledge or accommodate it to their cognitive structures. These processes are connected to exchange of information mainly in a verbal mode, but learning is also a process of mediation (Vygotsky, 1978) which also is very much related to students' prior knowledge, word pool, or linguistic abilities.

That means the learners should not be viewed as passive recipients of knowledge but rather as active participants in its creation (Bodner, 1986; McDermott, 1991). The pedagogy implemented by the teacher should use methods to encourage the students to construct their own knowledge in an active process of exchange with others (see Chapter 7).

Learning the language of chemistry

Knowing the language of a subject is a necessary component for understanding it (Hodson & Hodson, 1998). This language is new to the students and the learning of scientific language can be understood as learning of a foreign language (Childs & O'Farrell, 2003). However, the difference is that learning a foreign language means to learn new terms for phenomena that are already known. To learn the language of chemistry means that the phenomena and the ideas should be learned in parallel to the technical terms behind them.

A chemistry teacher has to be aware that all the teachers are influencing the development of linguistic skills. The teaching of any subject – e.g. chemistry – will interact with the development of students' general language abilities. But, the chemistry teacher will be the only one acquainting the students with the special language of chemistry, preparing the students to become able to follow further education in chemistry or to participate in societal debate about chemistry in future. "Speaking chemistry" is inseparable from learning its technical terms, symbols, or syntax of structuring information, e.g. in a write-up of an experiment (see Chapter 7).

As mentioned previously, the learning of scientific language is very difficult because students do not only have to learn the vocabulary and the semantics they also have to develop an understanding of the phenomena and theoretical concepts behind the terms. The students are in quite a different position than the one of the teacher, when learning about a new topic, as they do not have any specific knowledge about it, and therefore of the language used when discussing the topic (Johnstone & Wham, 1982). In principle, it takes a considerable amount of time and effort to learn and become fluent in a new language. Due to the coupling of learning the language and its contents in parallel, the process is even more difficult and might be more complex in several respects. One difficulty is that the students might feel familiar with some expressions of the language of chemistry without being aware of the differences in meanings of these expressions to how they are used in everyday life. But, in chemistry there are also many differences between the students' language and the scientific language. For example, the language in chemistry:

– Changes the meaning of words from their everyday life use towards a specific scientific context, e.g. matter, solution, element,

– Uses technical and special vocabulary of science (e.g., names of laboratory equipment), rarely met in everyday life, which is like learning foreign language vocabulary,
– Introduces a special symbolic language of science, particularly chemistry, with an alphabet (element symbols), words (chemical formulae) and sentences (chemical equations),
– Applies mathematics often connected to abstractions (e.g., equations, operations) with another specialist vocabulary,
– Asks for interpretation and labelling of graphs, diagrams, flow charts etc. within a scientific context, or
– Operates specific logical argumentation patterns in scientific arguing and writing, e.g. in a laboratory-report.

Some of the problems should be discussed in more detail. Within every subject lies a specific "register" of specific terms which is defined as "*a set of meanings that is appropriate to particular function of language, together with the words and structures which express these meanings*" (Halliday, 1975, p. 65). The scientific register contains many components including signs and symbols, scientific language (e.g., names of apparatus and chemicals), and everyday language (Figure 1).

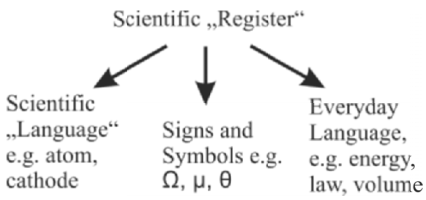


Figure 1. The different components of the scientific register (Broggy, 2009)

A large number of the terms in the "chemistry register" are taken from everyday life but with different meaning (Table 1). Scientific vocabulary can include words we use throughout our lives in everyday language but which are adapted to more specialised purposes in science and as a result will have different meanings within the scientific context (Johnstone & Selepeng, 2001; Lemke, 1990). The chemistry register is full of such specialist and non-specialist terminology, terms, and words. Students will be familiar with some of them as they will not be unique to science. However, these words have more specialised purposes in science and students will be unfamiliar with their new meaning. It is the hidden double meaning of the words that causes difficulties as the students are not aware of the whole spectrum of meanings, or do not know which meaning to use in a specific context. For example, Schmidt (1991) showed that when using the word 'neutralisation' students see the persuasive role of the word. He found that students when using the word 'neutralisation' they often think of a neutral solution as defined by chemists.

Table 1. Scientific words with dual meaning

Word	***Scientific meaning***	***Everyday meanings***
Effect	Something caused by an agent or scientific phenomenon	(often confused with affect) In fact, become operative – many meanings
Volume	Space occupied by an object	Loudness of music
Crude	Rough measurement or impure substance	Rude
Transfer	Move from one thing to another	Football market
Complex	Complicated or chemical compound of metals	Psychological condition
Initial	The beginning	A short signature
Substitute	Replacement	Extra football player
Dependent	Related variable	Relying on someone
Tendency	Predicted behaviour or relationship	Psychological preference
Agent	An active ingredient	James Bond, secret agent
Rate	Speed of a reaction	Council taxes
Mass	Weight	A lot, or a religious ceremony

Thus, the learning of scientific terms is often not only the learning of new scientific terms but also involves challenging students' alternative everyday conceptions, "fighting" these and trying to change them in the right direction.

The formation of full sentences and writing of text is a further issue which must be taken into account when considering scientific language. Scientific language is constructed through the use of specialised grammar (Gibbons, 2009). The language used in the textbook is often not the language used by the students and can be different to the language used within the classroom (Lemke, 1989). Steinmüller (1988) came to the conclusion that it is more difficult for students to speak in complete scientific sentences than to understand the scientific vocabulary. That is why he concludes that the language promotion in science lessons should contain parts of the general-linguistic area relating to morphology and syntax.

A further consideration that needs attention when teaching chemistry is the level of texts used for explanation and discussions. Language in chemistry is different from everyday life. E.g., chemists usually use only present tense in their texts and mainly ignore the past tenses or future tenses and science texts at all levels are full of new, long and difficult words, which are hard to spell and pronounce (e.g. the name of the indicator phenolphthalein). As soon as students enrol in a science classroom they are greeted with a science textbook that provides scientific knowledge in the form of scientific language. However, by the end of the course students should be able to read and comprehend the scientific text.

Understanding scientific texts is the ability to read, understand, and reason about scientific information conveyed in different genres is an important aspect of scientific literacy. One classification of genres is the distinction between narrative texts and expository texts. The common text in science textbooks is the expository – the text is informative and presents factual science content (Norris & Phillips, 1994). Thus scientific sentences are much shorter then sentences in everyday life or novels but bring an enormous abundance of content. The sentences are simple, short, and packed with information.

In the end we must consider introducing formal language as learning a new language. Research indicates that there are significant differences between the daily and non-formal language of young children and adolescents. Furthermore, the non-formal language includes the academic language that is typical to school lessons in general and to the language used in science lessons in particular. The scientific language used in school lessons includes specific characteristics that impact the learning and the discourse in science classes (Snow, 2010; Yore & Treagust, 2006). For example, Cassels and Johnstone (1984) showed that the level and number of scientific terms used in the teaching materials influence students' understanding and verbal reasoning ability. Additionally they showed that the maximum use of scientific terms happened in the laboratory phases because of the naming of equipment and describing observation during experimentation. The authors concluded that the experimental parts of the lesson enhance the complexity of student communication.

We expect our students to pick up chemistry by absorption but to most of them chemistry is like a foreign language, which they do not speak and in many cases do not want to learn. Biology and chemistry are particularly rich in difficult and polysyllabic words, from words like photosynthesis and polysaccharide in biology to electrolysis and polymerization in chemistry. The teachers as 'experts' do not notice the difficulty. They are familiar with the language (and the concepts behind the terms) and too often fire new words at the students nonstop. The students are deluged and shell-shocked and do their best to copy them down correctly, but they often try to 'learn them off' without understanding their meaning.

Scientific words are largely based on Greek and Latin words, but these languages are no longer part of common school subjects, and so modern students do not understand their structure. It can help learning if we point out some of the common prefixes and suffixes used in science as clues to meaning and aids to memory: for example, if a word starts with poly- then it means many something's (polymer, polysaccharide); the ending -ase indicates an enzyme (catalase, amylase) and the ending -ose a sugar (sucrose, lactose). Furthermore, a lot of words are put together from two words. Another problem is that even these technical terms sometimes have different correct meanings (e.g., oxidation) or synonyms (e.g., neutralisation, particle …) (Childs, 2006). Scientists often use terms already defined and apply them to newly discovered phenomena. Those terms are then defining both old and new meanings (Table 2). Learning about this change in meaning can help to learn about the nature of science, but sometimes it will confuse the students even more.

Table 2. One word defining different phenomena

Word	***Different meanings***
Matter	1. Atom 2. Molecule 3. Particle with a mass
Oxidation	1. Loss of electrons 2. Increase in oxidation state 3. Adding oxygen to form a oxide
Acid	1. A substance containing hydronium ions 2. A species that donates a proton (a proton donator) 3. A species that accepts a pair of electrons from another species (an electron pair acceptor)

Also, correct spelling matters in science even more that it does in language teaching and creativity is not a substitute for accuracy in science lessons. Incorrect spelling can cause problems and lose students grades, but in science (especially chemistry) one letter can change the meaning totally, e.g. alkanes, alkenes, and alkynes. In some contexts this can cause major safety problems, e.g. reading the name wrongly in an instruction or on a bottle can cause dangerous explosive reactions. Is it magnesium or manganese that is needed? As a change in a letter can change the meaning of a word or technical term, this could be even more the case when coming down to the reduced level of chemistry language: its symbols and formulae. Is it Mg or Mn that we need? Is it harmless H_2O or strongly corrosive H_2O_2 we are working with? Sometimes it is only one letter or a number that makes a big difference. Therefore, the chemistry teacher always should insist on correct spelling and test it, both on the level of words and sentences, as well as on the level of formulae and equations. We need to penalise mistakes and, set a good example ourselves (check all written work carefully for correct spelling and correct formulae).

Yet, spelling is not an end in itself and not only an issue due to the question of safety. Correct spelling is part of linking words to their meaning and correct use. Correct spelling is needed for clear, accurate communication in science, complementing accurate recording of measurements. Roughly right in science is wrong. There are no better examples to use than roughly complete chemical formulae that forget a letter or number. Forgetting or exchanging a letter or number within a formula can make an expression 100% wrong, or even worse changing the meaning to something that does not make sense. If a teacher spells a word or formula incorrectly and the students write it down, that error will propagate and even despite the teacher later correcting the mistake, some students will continue to use the incorrect spelling or formula.

The choice of the "right" level of language in science lessons is not an easy decision. The intelligibility, scientific correctness, and adequate placement of scientific language are the points that have to be kept in mind. Starting with scientific language at an early age might help the students to understand the lessons. A strong focus on everyday language might make students miss learning scientific language. It is important for the chemistry teacher to be able to express himself on different linguistic levels, through the language of everyday life, scientific language, pictorial-concrete and abstract, and to be aware of the switch between the levels and to make them explicit.

Linguistic heterogeneity in chemistry classes

In many countries, multilingualism is requested for today's global business world and community. On the other hand multilingualism in the context of school is seen as a potential source of deficits and problems. In the 1990s Aikenhead (1997) discussed linguistic issues in the case of Native Americans and the consequences for their education. Also since the TIMSS- and PISA-studies students' linguistic issues received more attention in political and educational discussion, also with a focus on chemistry education (Lynch, 2001).

In a lot of cases multilingualism (often bilingualism and semi-bilingualism) is to most of our students a disadvantage (Pollnick & Rutherford, 1993; Johnstone & Selepeng, 2001). Quite often this disadvantage is linked with a migration background of the students. This is the case for countries where students coming mainly from a second generation of immigrants, as well as countries like Australia or Israel where pupils with migration backgrounds are mainly new immigrants and thus frequently have interrupted education biographies. In both cases migration families often maintain immigration communities speaking between themselves their original language and cultural assimilation into the new society is slow and partial. As a result the students often reach lower levels of linguistic competence (lower than the national norm) and achieve lower levels of education than native speaking students (Lee, 2001).

Collier (1987) analysed seven factors influencing students' educational success for those coming from a migration background: (a) students' age of arrival, (b) length of residence in the country, (c) grade of entry into new school, (d) first reading and writing literacy skills, (e) formal educational background, (f) family's educational and socio-economic background, and (g) students' former exposure to the new country's life style. Reich and Roth (2002) found that students who hold high competencies in their mother tongue, when they enter into the school system in the new country, also achieve good proficiency when learning their new 'official' language, and the development of the mother tongue became secondary. However, only in few cases they reach a standard of a native speaker. There are different answers science education has to offer. Spillane, Diamond, Walker, Halverson, and Jita (2001) discussed how the school principal together with science teachers can cause change in science lessons. The following factors influence the change of science lesson at school: (a) physical resources (i.e., money and other material assets), (b) human capital of teachers and school leaders (i.e., the individual knowledge, skills, and expertise that form the stock of resources available in an organisation), and (c) social capital (i.e., the relations among individuals in a group or organisation, and such norms as trust, collaboration, and a sense of obligation). However, to make change happen, there is also need for collaboration between all the teachers at school, especially those who are resistant to change (Gamoran, Anderson, Quiroz, Secada, Williams, & Ashmann, 2003). Also, the programme and the organisation of the school is an important factor in this context. In schools with strong academic focus and stronger orientation on student-centred teaching (see Chapter 7) the differences in school achievement between students with and without migration backgrounds are much lower than in other schools (Lee & Smith, 1995). In these types of schools science teachers are generally working more in professional collectives. Such collective work affects the quality of science teaching (Lee, Smith, Croninger, & Robert, 1997). Typical characteristics for such professional collective are the strong cooperation of the science teachers, their cooperative development of ideas and their following of same goals (Lee & Smith, 1995). Finally, Markic (2011, 2012) concluded that the cooperation between chemistry teachers and language teachers offers a good opportunity to develop new teaching materials concerning linguistic heterogeneity of chemistry students. Furthermore, this project shows that the collaborative development of chemistry lesson plans by chemistry teachers and language teachers seems to be a promising way to create motivating and attractive learning environments that allow teachers to help students not only to learn chemistry but also to improve their knowledge and competencies in language.

But the issue of linguistic heterogeneity is not only an issue connected to migration. It has been found with increasing frequency that native speaking students have less developed language abilities in many countries (Cassels & Johnstone, 1983; Johnstone & Selepeng, 2001). The reasons for this can stem from the special needs of some of the students. Problematic familial and social backgrounds can lead to lower levels of linguistic abilities, which directly influence the student's learning success in any domain of school education, e.g. in chemistry.

Learning the language of chemistry is a challenge for most students. This is even more so the case for students with less developed linguistic skills, because these students often do not know the rules of the spoken and written language (Howe, 1970; Johnstone & Selepeng, 2001). Seedhouse (2004) showed that those students rarely have the opportunity to participate actively in regular classes. They experience the language passively, and have less opportunity to participate, and to develop their linguistic competencies. Furthermore, their under-developed language abilities make the learning of content difficult. These students barely understand any of their regular chemistry classes. They are not only asked to learn the content, they also have to cope with the language in general and the specific language of chemistry in particular.

Today, special pedagogies and tools are available to support students with linguistic problems in their learning of chemistry. General strategies are, e.g.,

– Use of pictorial explanation, e.g. providing laboratory tasks by a sequence of pictures instead of text,
– Providing aids for formulating sentences,
– Offering support for easier writing and understanding of texts, and
– Strengthening innovative teaching methods, like cooperative learning (see Chapter 7).

Examples from the classroom will be discussed in the practical section of this chapter. These examples will have the potential to help both types of students, those who have developed linguistic abilities and those who have not.

THE PRACTICE OF CHEMISTRY TEACHING

Planning chemistry lessons with recognition of linguistic issues

Dealing with linguistic issues in chemistry classes might start from the following ideas (Henderson & Wellington, 1998):

– *Introduce terms in different modes*: Introducing technical terms and formulae to students at the beginning is not beneficial to the students, as it may cause confusion. First, the students need to understand the phenomena or matter before they can name it. New terms can be introduced by phenomena, experiments, or pictures. Present the new term in different representational forms (not all students learn the same way).
– *Use activities, visual tools and vocabulary/semantic tools for learning words and terms*: Games, quizzes, or written tasks can help to better learn and memorise new words and terms. Examples are given below.
– *Use new terms at the right dose*: It is important not to introduce too much technical terms at once. In some lessons more than 10 new scientific words are presented to the students. Before implementing new words, it is important to ask yourself are really all the new scientific terms necessary and how often will they be used in the following lessons?
– *Help safeguarding new terms and structures*: After introducing new words, it helps if the teacher lists all new words covered in a lesson on the board (or on a poster) making sure students can spell them correctly, know their meaning, and where possible, know something about the structure of the words.
– *Teach new terms by training*: After implementing new terms it is important to use these words well. Different games and exercises should follow after the introduction. Anyhow, games should make sense, but be short. Trainings in homework might help as well as short repetitions in the beginning of each single lesson, or face to face recitations among the students.

– *Use language situation-oriented*: It is important for a teacher to reflect about their own language use during the lesson. While talking in class, the teacher should use "school language". The teachers should speak in full sentences, speak slowly and take breaks between the sentences. It should not be too scientific but should also not be colloquial. The teacher should limit the use of ironic statements and wordplay. Such word play is difficult for young students, and those with limited linguistic skills to understand.
– *Address linguistic mistakes*: It is important that teacher notices mistakes made by the students and address them. One method is that students say or read the sentence again and maybe they then will notice the mistake on their own. Also the teacher can repeat the sentence and follow it with the corrected one. The students can analyse the mistake and reflect on it.
– *Introduces exercises carefully*: The teacher should not use unknown words in exercises. Write short sentences and take care not to formulate more than one question within one exercise.

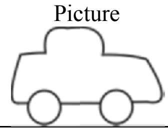
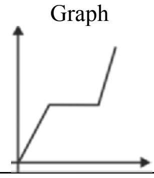
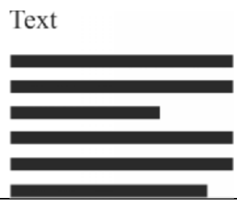
Level of Object	Object 
Pictorial Level	Picture 
Symbolic Level	Graph 
Linguistic Level	
Mathematical Level	Formula *NaOH* H_2O H_3PO_4

Figure 2. Different representations and their levels (Leisen, 2005)

– *Layout texts carefully*: One of the key points often not considered by teachers is a layout of the texts. Often work sheets are long and crowded. However: less is more. Keep sentences short; reduce the amount of text to the necessary minimum. Give the text structure. Organise the text clearly through the use of paragraphs and sub-headings. Leave space for students' comments.
– *Limit the number of new words*: Try to cut the number of the new words and unnecessary names of materials and apparatus. Ask yourself, do you really need those words and are they important for understanding of the procedure of the activities in the present lesson or lessons that will follow.

Visual tools to facilitate better comprehension of words and concepts

There are different forms in which knowledge can be presented. Leisen (2005) identifies five different representational forms that differ in their level of abstraction: (a) level of object, (b) pictorial level, (b) linguistic level, (d) symbolical level and (e) mathematical level (Figure 2). The abstraction increases from level (a) to (e).

On the other side, not all children learn the same way. Therefore, the materials should be presented in different forms, so that (almost) all learning styles are considered. As we see from Figure 2, the pictorial level should be used in order to achieve the linguistic level.

Picture story. In a picture story (Figure 3) the pictures are supported by speech bubbles. The picture story can be given as a whole, or some parts or speech balloons of the picture can be missing. Using speech balloons can help to reduce the demand on the students. This method is very attractive for students because it is short, concise, and taken from students' life. Students are familiar with speech balloon from comics. They can be allowed to use their everyday language, simple sentences, and non-scientific words here.

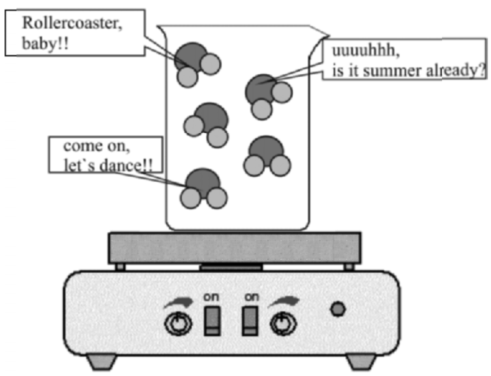


Figure 3. Picture story for water molecules in the gaseous state

Sequence of pictures. A sequence of pictures is an order of pictures that shows a process (Figure 4). Analogous to a movie, a chronological action is presented. The pictures help pupils to verbalise an experimental procedure and to understand the process. To differentiate between the students, it is also possible for some of the steps of the experiment to be presented as a picture and the others to be written as text. The students should change in this case from one representational form to another. In case the students are not familiar with the scientific vocabulary and the names of the instruments, cards can be used to assist the students' understanding. The indication of the beginning of the sentence or a cloze can be included in this sequence of pictures as further help.

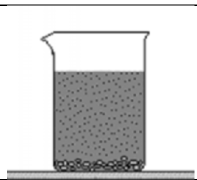
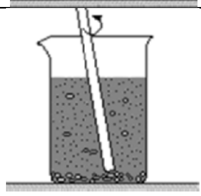
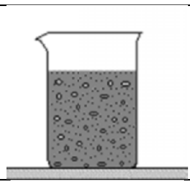
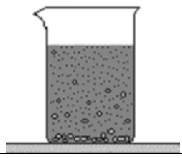
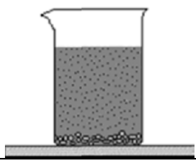
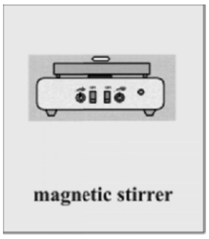
Drawing	*What happened?*
	The water ____________________ __________________________ The sand _____________________ __________________________
	The glass rod _________________ __________________________ The water ____________________ __________________________ The sand _____________________
	The water ____________________ __________________________ The sand _____________________ __________________________
	The water ____________________ __________________________ The sand _____________________ __________________________
	The water ____________________ __________________________ The sand _____________________ __________________________

Figure 4. Sequence of pictures about stirring a sand-water mixture

Visual association. This approach uses terms that are connected with pictures, so called visual agents (Figure 5). These visual agents can be a picture of the term that should be learned. But, it is also possible to take things that students know from their everyday lives and have one of the properties that are characteristic for the new term. This tool is especially applicable for lower grades, e.g. when the names of instruments are to be learned.



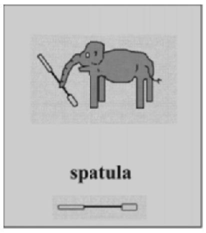


Figure 5. Visual association

Vocabulary and semantic tools

During an experiment, students often do not know how to write their observations. Sometimes words are missing; sometimes the semantics are poorly applied. Different tools can help students to better learn the necessary vocabulary, but also to practice correct semantics.

Catalogue of words. A catalogue of words contains all the important words and scientific terms which are mentioned in a certain lesson unit or as a part of it (Figure 6). Such catalogues can help pupils to write a piece of text on their own, making the process much simpler and easier (e.g., in a laboratory report). Furthermore, the number of words given (especially scientific terms), the direction and the content of the text can be influenced. Such catalogues can be supplemented not only by the explanation of the term/word but also by utilising pictures.

You can use following words to express your observation:

- *The holes*
- *The filter*
- *The strainer*
- *The size of the wholes*
- *The size of matter*
- *Stays inside*

Figure 6. Catalogue of words

Field of words. The field of words is a disordered arrangement of words or parts of sentences about one specific topic (Figure 7). For weaker students some words or parts of the sentence can be connected. However, the student should put the words in order, connect them, and finally write a sentence and the whole text. It is helpful that both the articles for the substantives and the irregular verbs are mentioned as well. A variation of the method is that students can make a field of words for each other.

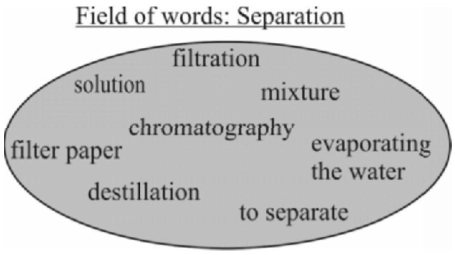


Figure 7. Field of words

Sentence puzzle. The pieces of a sentence are given (Figure 8). The students' task is to put the pieces together and to make one sentence. The same parts of the sentence should be the same colour e.g. verb = yellow, adverb = blue, … Using such a toy, the students repeat the content of the last lessons, but also build their knowledge through using the correct syntax.

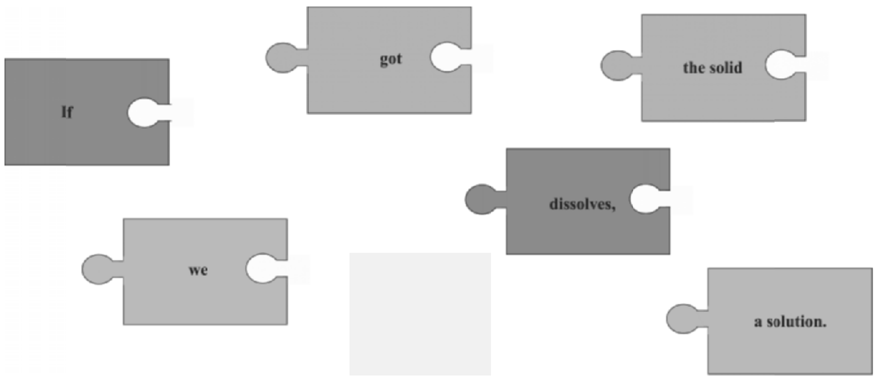


Figure 8. Sentence puzzle

Such a sentence puzzle does not need to be presented as a game. While this may be more fun for the students it can also be more work for the teachers. It is also possible to make a work sheet with the puzzle pieces and students should cut and connect them. To increase the level of the tool, the puzzle pieces should not be coloured but students should give the colour on their own before they start to build the sentences. Thus, the grammar can be repeated in this way.

If-then-sentences. If one wants to practice special science educational syntax, the students can make different examples of the sentence by repeating content as well. One example is the use of 'if-then-sentences' (Figure 9). The students get two simple sentences that should be combined. For 'if-then-sentences' the first sentence should contain the reason and the second sentence the consequence. By making one sentence out of the two, students are not only going to repeat the content but also practice the characteristics of the complexity of the sentence and the grammar of the language (e.g. where to put the verb in a sentence). Alternatively one can use this method for any kind of sentence, e.g. more/less … or neither … nor.

If		then
a mixture contains two layers.		I can use a magnet.
a mixture contains magnetic and non-magnetic compound.		I can do a filtration.
a mixture contains sand and water.		I can pour one layer off.

Figure 9. Example for if-then-sentences

The beginning of the sentence. Writing a sentence is often incredibly difficult for many students, however the most difficult part is usually starting the sentence. Typically students struggle with combining the first words of a sentence. By providing them with the beginning of the sentences it can help the students to write a sentence on their own and express their opinion and their knowledge about the topic. However, the beginning of the sentence is also an indication about the expected content. The number of words given at the beginning of a sentence should depend on the students' level of linguistic competency. Sometimes it is enough to give the first word of the sentence. It stimulates students to progress and the word serves as an incentive to organise the words in the student's head.

Block-diagram. In a block-diagram the different parts of a sentence (noun, pronoun, verb, conjugation, adverb, and adjective) are given (Figure 10). Students can use these parts compose the sentences and in doing so they can express their ideas and knowledge. Furthermore, it is possible that a column with scientific terms is also added. However, this can be decided by the teacher depending on the student's cognitive level. The block-diagram is especially useful for training students about the syntactical construction cooperated with scientific terms. It is important to note that the parts of the sentence given in a block-diagram are not parts of the specific sentences. There words should help students to build their own sentence. The block-diagram is an aid for a student if the word is "missing" while they were verbalising their own observation and knowledge.

	Verb	*Pronoun*		*Conjugation*
First	Heat	I	A	with
If	filter	you	the	in
From	solve	he/she/it	an	by
After that	stop	we	.	of
Finally	dissolve	they	.	so that
This	evaporate	.	.	.
To	is	.	.	.
.	can	.	.	.
..	.	..	..	..

Figure 10. Block-diagram

Activities for learning the technical language of chemistry

To speak "chemistry" it is important to speak the language of chemistry and to use its technical terms correctly. The following section will outline some tools on how to learn the technical terms in chemistry.

Explanation of the word. Explanation of the word means that students should take one word from their lesson (which can be known but also a new word) and they should present it in different representational forms. The word/term can be explained in a sentence that should be simple and should be presented as a picture, drawing, action, etc.

Cloze. A cloze (gap) text is a piece of scientific text which leaves some words out. The teacher should take care when organising the text to ensure that the words remaining will provide enough information to allow the student complete it. The task for the students is to find the right words to fit in the gap within the written text. For students with lower linguistic skills the missing words could be given to be puzzled into the cloze (Figure 11). This game can also be used for practising the use of the grammar and right syntax.

A chlorine atom has ________electrons in its outer shell. To achieve a stable ________ of eight electrons, two chlorine atoms share a __________of electrons with each other, i.e. a __________ bond is formed between the two ________. Thus, each atom has its own seven _______ electrons and a share in one of the outer electrons of the other atom.

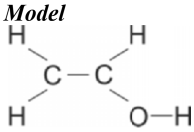
***Words to add*: pair, outer, covalent, atoms, octet, seven**

Figure 11. Cloze in chemistry lesson

Chinese whisper. Chinese whisper is a game that is well known in every country. The game typically involves a word or piece of information being whispered from one individual to another and so on, so that the word or the information reaches the final recipient, it has often changed completely from its original form. In this version of the game, the information should be pasted from one side to another by using different representational forms. The information should not be lost during the game. The students should work in small groups and every student is responsible in each cycle for one representational form. One word should be written on the paper and the first student should present it as e.g. a picture, second student as chemical symbol, etc. (Table 3).

Variations are possible, so as to allow the students to practice communication and to increase their social skills. It is also possible that one group makes one representational form. Here the students in a small group have to discuss the best and most correct ways in which to present a particular word.

Table 3. Chinese whisper

Name	***Formula***	***Sentence about***	***Model***	***Name***
Ethanol	C_2H_5OH	Some people drink it.		Ethanol

Concept mapping. As discussed in Chapter 7 concept mapping is a practical learning tool which falls into the broad family of graphic organising tools that includes mind mapping and spider diagrams. The node-linked diagrams are very suitable for language learning as the key components are concepts and linking phrases that together allow one to represent their proficiency in scientific language and hence their conceptual understanding. The process of constructing maps can help develop literacy skills in two ways. Firstly when organising concepts and words you are forced to think about their spelling, meaning and how they connect to one another. Secondly, when constructing maps in cooperative groups the ongoing discourse and debate between students as they agree on the structure will allow them to practice the pronunciation of the scientific terms and the development of the map from one or two concepts to phrases will help develop students' proficiency and their ability to develop complex relationships between terms. For more details on concept maps and the related mind maps, see Chapter 7.

Learning formulae by inventing analogies. "Where should I put the number 2? At the beginning and should it be big, or in between the letters and small?" These are the questions that many teachers hear when they are teaching the formal language of chemistry. The way chemists read the formulae differs from how we read normally (e.g. H_2O = 2 hydrogen atoms and one oxygen atom). This can cause confusion among students. Analogies can be taken from everyday life as a help (Table 4; Heuer & Parchmann, 2008). If the students write down each atom that one molecule is composed of, they can then count the letters and made a formal word out of it.

Table 4. Analogies of everyday words with formula language

Word	***Components***	***"Formulae"***
Ball	B A L L	BAL_2
Summer	S U M M E R	SUM_2ER
Water	H O H	H_2O
Methane	C H H H H	CH_4
Sodium hydroxide	Na O H	NaOH

Domino or memory games. Almost every student knows the rules of the domino game. The domino tiles should be placed together so that the sides of the domino match to each other. However, it is important that the connection between the two tiles is clear. The domino tiles should contain different representational forms, not only words (Figure 12). To ensure that the domino tiles are in the correct sequence, the domino tiles should end up forming a circle. A similar approach is used in the memory game. Memory is a card game in which different cards have various images, figures, signs, formulae or notes on them (Figure 13). The key to the game is finding a matching pair. A matching pair is a pair which is illustrating the same thing, though it may be through different means. The students should find the pair of cards that illustrate the same concept of idea, for example one card may display the name of a substance and the other one a picture of it, sketch or formula. The student with the highest number of pairs is the winner of the game.

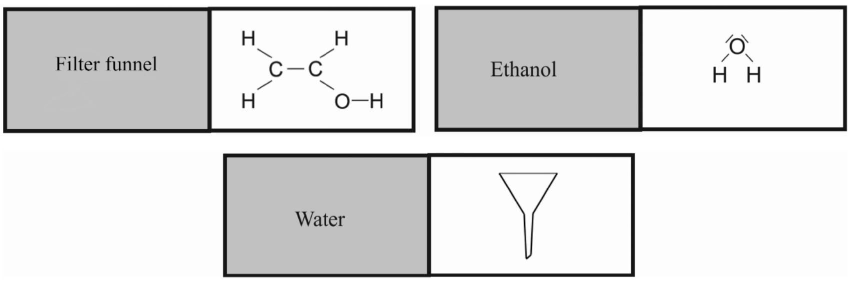


Figure 12. Domino

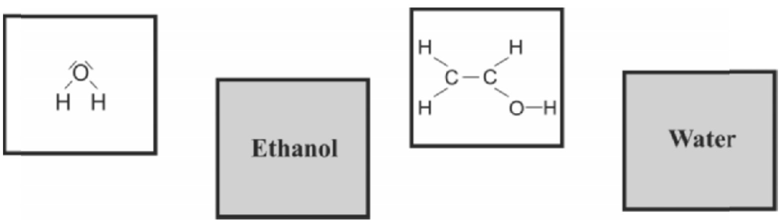


Figure 13. Memory game

SUMMARY: KEY SENTENCES

– Language is the basic mediator of information transfer and meaning-making in learning in general and in chemistry education in particular.
– Enculturation into the language of chemistry is one of the essential preconditions for further chemistry learning and students' participation in societal debate about chemistry and technology related issues in the future.
– The language of chemistry is a new language for the students. It comprises a register of technical words, a specific syntax, and a whole world of unique formulae, signs, and graphical representations. Students have to develop in parallel their knowledge and understanding of the chemistry content, and their skills in using the right words and syntax.
– Recognition of linguistic issues, students' linguistic skills, and growing linguistic heterogeneity is essential for successful chemistry teaching and learning.
– Different linguistic tools offer help to promote students' skills in writing, talking, and understanding in the context of chemistry education.

ASK YOURSELF

1. Explain why coping with linguistic issues is so important for a chemistry teacher.
2. Sum up, as much as possible, potential linguistic problems that might occur during chemistry learning.
3. Take a book about psychology, mathematics, geology or any subject that you have not studied. Open it somewhere in the middle and read the page. Explain why this exercise is a good analogy to understand some of the essential learning problems of students in chemistry classes.
4. Outline a strategy to introduce ten different technical terms and names for equipment from the topic 'separation of matter' by using different tools made for coping with linguistic issues in the chemistry classroom.
5. Take three worksheets of your choice from the Internet on the topic of introducing atomic structure. Check whether you are able to analyse the materials concerning potential linguistic barriers for effective chemistry learning. Develop a new work sheet that takes into consideration linguistic issues of chemistry learning.

HINTS FOR FURTHER READING

Miller, J., Kostogriz, A., & Gearon, M. (2009). *Culturally and linguistic diverse classrooms. New dilemmas for teachers*. Clevedon: Multilingual Matters. The book is a collection of papers from well-known language education scholars who present their research in a range of international setting. The texts raise a different issues about working in linguistic and culturally diverse classrooms.

Snow, M. A., & Brinton, D. M. (1997) *The content-based classroom: Perspectives on integrating language and content.* New York: Longman. The book presents a good understanding of how to apply the tenets of a content-based approach to language teaching with learners of different ages and proficiency levels.

Hodson, D. (2009). The language of science and science education. In D. Hodson (ed.), *Teaching and learning about science. Language, theories, methods, history, tradition and values* (pp. 241-282). Rotterdam: Sense. The chapter adresses some key issues relating to the distinctive language of science.

Fathman, A. K., & Crowther, D. T. (2006). *Science for English language learners: K-12 classroom strategies*. Arlington: NSTA. The book provides a comprehensive foundation for teaching both science and language.

Rosebery, A. S., & Warren, B. (2008). *Teaching science to English language learners: building on students' strengths*. Arlington: NSTA. The book addresses the question whether a students' cultural background supports learning ins science and weather concentrating on the specialised vocabulary of science is the best way to help English language learning students.

Stoddart, T. Pinal, A., Latzke, M., & Canaday, D. (2002). Integrating inquiry science and language development for English language learners. *Journal of Research in Science Teaching*, *39*, 664-687. The report describes a conceptual framework for science–language integration and the development of a five-level rubric to assess teachers' understanding of curricular integration.

RESOURCES FROM THE INTERNET

Language in science: *www.fdavidpeat.com/bibliography/essays/lang.htm*. A. Ford and F. Peat discuss a research project which investigates the hypothesis that language plays an active role in the development of scientific ideas.

Special Online Collection on Science, Language and Literacy: *www.sciencemag.org/site/special/education2010/*. In this special issue, the editors have collected a variety of articles that focus on language and literacy in science. The term represents two angles of the problem: knowing what science has discovered and being able to communicate in the language of science.

Foreign languages in African science classrooms: *www.deta.up.ac.za/papers_presentations/Oyoo%202011DETA%20PAPER_DrSamuelOumaOyoo_paper.pdf*. S. Ouma Oyoo, presents the outcome of sustained literature reviews of cross-national research on language in science education over the last 40 years.

Using everyday language to teach science may help students learn: *news.stanford.edu/news/2008/august20/teachsci-082008.html*. K. J. Sullivan presents two approaches of teaching science considering language and makes a comparison of it.

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AVI HOFSTEIN, MIRA KIPNIS & IAN ABRAHAMS

6. HOW TO LEARN IN AND FROM THE CHEMISTRY LABORATORY

Laboratory activities have long had a distinctive and central role in the chemistry curriculum as a means of making sense of the natural world. For many years chemistry educators have suggested that many benefits accrue from engaging students in the science laboratory. The wide written array of literature illustrates that, the laboratory provides a unique mode of instruction, learning, and assessment. This chapter provides a theoretical overview justifying learning in and from the laboratory in chemistry education and discussing its educational potential. The theoretical discussion is followed by a more practical part that deals with various approaches to the chemistry laboratory, the teachers' behaviour in the laboratory, assessment of students' achievement and progress, and other related organisational and educational variables.

THEORETICAL BASIS

While reading a textbook of chemistry, I came upon the statement, 'nitric acid acts upon copper' ... and I determinate to see what this meant. Having located some nitric acid ... I had only to learn what the words 'act upon' meant. In the interest of knowledge I was even willing to sacrifice one of the few copper cents then in my possession. I put one of them on the table; opened the bottle marked 'nitric acid,' poured some of the liquid on the copper; and prepared to make an observation. But what was this wonderful thing which I beheld? The cent was already changed, and it was no small change either. A greenish blue liquid foamed and fumed over the cent and the table. The air ... became coloured dark red. How could I stop this? I tried ... by picking up the cent and throwing it out the window ... I learned another fact; nitric acid acts upon fingers. The pain led to another unpremeditated experiment. I drew my fingers across my trousers and discovered nitric acid acts upon trousers. That was the most impressive experiment I have ever performed. I tell of it even now with interest. It was a revelation to me. Plainly the only way to learn about such remarkable kinds of action is to see the results, to experiment, to work in a laboratory.

Ira Remsen (1846-1927), chemist and inventor of the saccharin, when he was at the age of 12 (cited from Hauber & Rayner-Canham, 2004)

I. Eilks and A. Hofstein (eds.), Teaching Chemistry – A Studybook, 153–182.

The history of the laboratory in school chemistry education

Throughout the chapter we use the terms *practical work*, which is common e.g. in the UK context, and *laboratory work*, which is common in the USA, interchangeably. A precise definition is difficult as these in school practice embrace an array of activities, but generally they refer to experiences in school settings in which students interact with equipment and materials or secondary sources of data to observe and understand the natural world.

Laboratory activities have long had a distinctive and central role in science curricula as a means of making sense of the natural world. Since the nineteenth century, when schools began to teach science systematically, the laboratory has become a distinctive feature of science education. For many teachers and curriculum developers the science laboratory belongs in science learning as obviously as naturally as the gardening belongs in the garden and the cooking belongs in the kitchen (Solomon, 1980). After the first-world-war, and with the rapid increase of scientific knowledge, the laboratory was used mainly as a means for confirming and illustrating information previously learnt in a lecture or from textbook. With the reform in science education in the 1960s (see Chapter 1) in many countries the ideal became to engage students with investigations, discoveries, problem solving activities and inquiry. The *National Science Education Standards* (NRC, 1996, p. 23) defines scientific inquiry as

> the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Scientific inquiry also refers to the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world.

In other words, the inquiry laboratory became the core of the science learning process (Shulman & Tamir, 1973).

For many years science educators (in our case chemistry educators) have suggested that many benefits accrue from engaging students in science laboratory activities (Hofstein & Lunetta, 2004), e.g. Tobin (1990, p. 405) wrote that: "*Laboratory activities appeal as a way of allowing students to learn with understanding and at the same time engage in the process of constructing knowledge by doing science.*"

In projects developed in the 1960s, the laboratory was intended to be a place for inquiring, developing and the testing of theories as well as providing students with the opportunity to 'practice being a scientist.' George Pimentel (see Merrill & Ridgeway, 1969) noted that in the *CHEMStudy* project, which was developed in the 1960s in the USA, the laboratory was designed to help students gain a better idea of the nature of science (NOS) and scientific investigation (see Chapter 1).

Many research studies (summarised by Hofstein & Lunetta, 1982) were conducted with the goal in mind to explore the effectiveness of the laboratory for attaining the many objectives (both cognitive, affective, and psychomotoric; see Chapter 2) that had been suggested in the science education literature.

The traditional list of objectives to be attained by including laboratory work into chemistry teaching includes:
– Understanding of scientific concepts,
– Interest and motivation,
– Attitude towards science,
– Scientific practical skills and problem solving abilities,
– Scientific habits of mind,
– Understanding the nature of science (NOS), and
– The opportunity to do science.

Over the years hundreds of papers and essays were published with the goal being to explore and investigate the uniqueness of the science laboratory in general and its educational effectiveness in particular. In addition, it has been widely believed that the laboratory provides the only place in school where certain kinds of skills, abilities, and understanding can be developed (Lazarowitz & Tamir, 1994). In other words, as Kerr (1963) has suggested, the laboratory provides a unique mode of instruction, learning, and assessment.

Precisely what kind of objectives and aims will be attained in the laboratory is dependent on a wide range of factors. We suggest that, amongst others, these will include the teacher's goals, expectations, subject and pedagogical content knowledge (PCK) (see Chapter 10) as well as the degree of relevance to the topic (see Chapter 1), the students' abilities and interests (see Chapter 3), the methods of how the laboratory activity is embedded into the learning process (see Chapter 7), and many other logistical and economic considerations related to the school settings and facilities. Table 1 is an attempt to summarise the various goals for laboratory activities.

Table 1. Suggested goals for laboratory activity (Bennett, 2003, pp. 78-79)

Goals for laboratory activity
to encourage accurate observation and description
to make scientific phenomena more real
to enhance understanding of scientific ideas
to arouse and maintain interest (particularly in younger pupils)
to promote a scientific method of thought

It should be noted that some of these goals, such as *"to enhance understanding of scientific ideas*" coincide with the broad goals of science education that are not necessarily laboratory based. The teacher should be in the position to judge whether the laboratory is the most effective learning environment for attaining a certain objective while teaching a certain topic. Teachers should be aware that there has been a great deal of discussion and numerous research studies about which goals are in fact better achieved through laboratory instruction than through other instructional (pedagogical) approaches (Hofstein & Lunetta, 2004). The many research studies and essays that were cited in these (and other publications) criticised the tradition of conducting experiments without clear purposes and goals.

In addition, they revealed a significant mismatch between teachers' goals for learning in the science laboratory and those that were defined by curriculum developers and the researchers in science education. In other words, teachers' interpretation of the aims and objectives of learning in laboratories differs from those specified by the curriculum developers who developed the laboratory activities.

The role of the experiment for the generation of knowledge in science and in science education

In the last fifteen years we have seen major changes in science education. This is caused partly by globalisation and rapid technological development, which calls for educational systems with high quality of science content not only to meet international competition, but also to develop the right knowledge and competencies that are needed in the modern society (see Chapter 1). In the USA, we have seen development regarding standards for science education (NRC, 1996) in which there was clear support for inquiry learning both as content as well as higher order learning skills. The standards included in the context of the laboratory the following skills: planning of an experiment, to observe, asking relevant questions, hypothesising, and analysing experimental results (Bybee, 2000). In addition, it was observed internationally that there has been a high frequency of curriculum reforms. A central point has been to make science education better adapted to the needs of all citizens (AAAS, 1990).

It is recognised that citizens' needs include more than just understanding scientific knowledge. In everyday life science is often involved in public debate and used as evidence to support political views. Science also frequently presents findings and information which challenge existing norms and ethical standards in society. Mostly it is 'cutting edge' science and not established theories that are at play. For this reason it does not help to know 'text book science,' but rather it is necessary for knowledge *about* science (see also Chapters 1 and 2). Citizens need to understand principles in scientific inquiry, how science operates at a social level (Millar & Osborne, 1999), and about the relationship between science and its use for societal purposes (Eilks, Nielsen, & Hofstein, 2012). The natural question, of course, is to what degree and in what ways the science laboratory can help provide students with such understanding.

Another area of change in the recent period has been a further development of the constructivist perspectives into socio-cultural views of learning and of science (see also Chapter 7). The *socio-cultural view of science* emphasises that science knowledge is socially constructed. Scientific inquiry, accordingly, is seen to include a process in which explanations are developed to make sense of data and then presented to a community of peers for critique, debate, and revision (Duschl & Osborne, 2002). This re-conceptualisation of science from an individual to social perspective has fundamentally changed the view of experiments as a way of portraying the scientific method. Rather than seeing the procedural steps of the experiment as "*the scientific method*," it is now valued for the role it plays in providing evidence for knowledge (Newton, Driver, & Osborne, 1999).

It is believed that thinking processes originate from socially mediated activities (see Chapter 7), particularly through the mediation of language (see Chapter 5). As a consequence science learning is seen as socialisation into a science culture (Driver, Newton & Osborne, 2000). Students therefore need opportunities to practice using their science ideas and thinking through talking with each other, and the science teacher. All these changes have obvious relevance for practical work. Rather than training science specialists, the laboratory should now help the average citizens understand *about* science and develop skills useful in evaluating scientific claims in everyday life. Rather than promoting "*the science method*," the laboratory should focus on "*how we know what we know and why we believe certain statements rather than competing alternatives*" (Duschl & Grandy, 2008). The social-cultural learning perspective also offers incentives to re-visit group work in the school laboratory (see the discussion on cooperative learning in the lab in Chapter 7). However perhaps the reason, is that the current changes have finally produced an alternative to the science process approach and the structure of the discipline approach (Millar, 1989) established in the western world more than 50 years ago. We now experience a new rationale for understanding science inquiry and how this may link with laboratory work at school.

The chemistry laboratory: A unique learning environment

Laboratory activities have long played a distinctive and central role in the science curriculum and many science educators have suggested that many benefits accrue from engaging students in science laboratory activities (Hofstein & Lunetta, 1982, 2004; Tobin, 1990; Lunetta, 1998; Lazarowitz & Tamir, 1994; Lunetta, Hofstein, & Clough, 2007). More specifically they suggested that when properly developed, designed, and structured, laboratory-centred science curricula have the potential to enhance students' meaningful learning, conceptual understanding, and their understanding of the nature of science. In addition, the literature reveals a clear correlation between students' attitudes towards learning science and various modes of instruction in the science laboratory. There is also some evidence that students find practical work relatively useful and enjoyable when compared to other science teaching and learning activities. In a survey conducted among 1400 students in the UK (of a range of ages) (Cerini, Murray, & Ambrosio, 2003), 71% chose 'doing an experiment in class' as one of the three methods of teaching and learning science they found 'most enjoyable,' a result that placed it third in rank order.

Although the literature does not provide a clear relationship between learning science and practical experiences in the laboratory (Hofstein & Mamlok-Naaman, 2011), many research studies conducted mainly during the 1960s and 1970s (summarised by Hofstein & Lunetta, 1982, 2004) reported that students enjoy laboratory work and that laboratory experiences resulted in positive and improved attitudes and interest in science (see Chapter 3). A recent publication (Hofstein & Mamlok-Naaman, 2011) summarised 50 years of research regarding the relationship between affective variables (attitude, interest, and curiosity) and enrolment in chemistry classes in the upper secondary schools around the world. It is beyond the scope of this chapter to mention all the studies that were conducted in this area, however it is worthwhile to mention a few. For example, Charen (1966) found that in general, laboratory work enhanced students' attitudes towards learning chemistry. Ben-Zvi, Hofstein, Samuel, and Kempa (1976) reported on a chemistry study in which chemistry students wrote that personal laboratory work (hands-on) was the most effective instructional method that they had experienced for promoting their interest in learning chemistry when contrasted with group discussion, teacher demonstrations, filmed experiments, and teachers' whole-class frontal lectures. A study aimed at exploring students' attitudes towards the chemistry laboratory (Okebukola, 1986) revealed that a greater degree of participation in laboratory work may produce more positive attitudes towards the laboratory. A study that focused on students' reasons for enrolling (and not enrolling) in more advanced (post compulsory) chemistry studies Milner, Ben-Zvi and Hofstein (1987) found that one of the key reasons for enrolling in chemistry courses was that students were able to participate in practical activities and thereby gained valuable manipulative skills. It is suggested that the decision to study (or not study) additional subjects (e.g., chemistry) is at least a partial attitudinal indication. Other studies (e.g. Berry, Mulhall, Gunstone, & Loughran, 1999) have found that students are more frequently motivated by practical work in which they are allowed to exercise some degree of control over the design and which they find both challenging and rewarding. Although Lazarowitz and Tamir (1994) suggest that the motivational effectiveness of such tasks can be reduced if it is perceived as too difficult.

In 2004, *The Attitude towards Chemistry Laboratory Questionnaire* (developed by Hofstein, Ben-Zvi, & Samuel, 1976) was used in a study in which two groups of high-school chemistry students were compared (Kipnis & Hofstein, 2005). The first group conducted inquiry-type experiments (Hofstein, Shore, & Kipnis, 2004), whereas the second group performed more conventional, confirmation-type activities. The students in the inquiry group developed more positive attitudes towards learning chemistry than did those students who had experienced a more conventional chemistry program.

However, irrespective of the claims that students prefer a laboratory centred approach (Hofstein et al., 1976; Lazarowitz & Tamir, 1994), and that its use encourages and motivates them to study science (Lazarowitz & Tamir, 1994), many teachers are only too aware of the fact that too few of their students opt to pursue science post compulsion (Millar & Osborne, 1999). Bennett (2003) notes that such results suggest that whilst certain practical tasks can generate interest and/or engagement within a particular lesson, there is little evidence to suggest that they successfully motivate pupils towards science in general or, more importantly, towards the further study of one (or more) of the sciences in particular.

Potentially, the greater concern is the fact that many students appear to be deciding not to pursue science (biology, chemistry or physics) even though, in many countries, a substantial proportion of science teaching time is devoted to undertaking practical work (House of Commons Select Committee on Science and Technology, 2002). Certainly, this is the worrying trend in the UK, where practical work is a traditional and well established part of science education. It has been suggested (Bennett, 2003) that there is little reason to believe that the amount of practical work will have diminished since it was reported (Thompson, 1975) that one third of all science teaching time, in the 17-18 age range, was devoted to some form of practical work, with this rising to one half of science teaching time for students aged 11-13 (Beatty & Woolnough, 1982).

Despite the many claims about the 'motivational' value of practical work it has been suggested (Abrahams, 2011) that, in a strict psychological sense, these claims are better understood in terms of situational interest (see Chapter 3). The fact that situational interest is, unlike motivation or personal interest, unlikely to endure beyond the end of a particular lesson (Murphy & Alexander, 2000) helps to explain why students need to be continuously re-stimulated by the frequent use of practical work. Once this fact is recognised the reason why many of those students who claim to like practical work also claim to have little, if any, personal interest in science, or any intention of pursuing it post compulsion, becomes clearer. For whilst students do like practical work their reasons for doing so appear to be primarily that they see it as preferable to non-practical teaching techniques that they associate, in particular, with more writing (Hodson, 1990; Hofstein & Lunetta, 1982). Furthermore it has been reported (Abrahams, 2011) that the proportion of students who claimed to like practical work for its own sake, as opposed to merely preferring it to writing, decreases as students progress through the school. The reason for this decrease was found to be not only the fact that the novelty of being in a laboratory environment wears off relatively quickly but that students become disillusioned by the reality of school science.

Research conducted over a period of almost 50 years showed that the laboratory has the potential to contribute significantly towards shaping and enhancing students' attitudes towards chemistry. How effective it will be in reaching that potential will depend upon the instructional approach adopted by both teachers and curriculum developers and by the teachers' behaviour and practice in their classrooms.

How are laboratories used? – Teachers' and students' practice

In order to find common practices and what is really happening in the chemistry laboratory classrooms, there is a need to take into consideration three distinct factors (Hofstein & Lunetta, 1982):

– Teacher's practice;
– The students' behaviour , and
– The type, level and nature of activity in which the students are engaged.

These factors play an important role in controlling and promoting the student's learning in the chemistry laboratory.

The teacher's practice. From research we know that teachers play a key role in what students learn. The best curriculum materials can result in limited student learning if a teacher is insensitive to the intended goals, to students' needs, and to the appropriate and availability teaching strategies. Interestingly similar issues have been reported by Black (2008) with regard to the widespread dissemination of assessment for learning (AfL) which suggests that the general roll-out of curriculum materials needs to be accompanied by widespread continuous professional development (CPD) (see Chapter 10). For example, if a teacher's goal is to teach measuring skills in the chemistry laboratory, and not just the facts that can be observed, this goal should be apparent in the things that they say and do.

Bryce and Robertson's (1985) review of the use of practical work in science education in different countries clearly showed that although many science teachers' articulated philosophies appeared to support a hands-on investigative approach with authentic (pedagogically effective) learning experiences, the classroom practice of those teachers did not generally appear to be consistent with their stated philosophies. Several studies have reported that very often teachers involve students principally in relatively low-level, routine activities (referred to frequently as 'recipe' style activities in which the students strictly follow recipes), and that teacher-student interactions focused principally and frequently on low-level procedural questions and answers. Marx, Freeman, Krajcik, and Blumenfeld (1998) in the USA reported that science teachers often have difficulty helping students ask thoughtful questions, design investigations, and draw conclusions from data. Similar findings were reported regarding chemistry laboratory settings (De Carlo & Rubba, 1994). More recently Abrahams and Millar (2008) investigated the effectiveness of practical work by analysing a sample of 25 "typical" science lessons involving practical work in English secondary schools. They conclude that the teachers' focus in these lessons was predominantly on making students manipulate physical objects and equipment. Hardly any teacher focused on the cognitive challenge of linking observations and experiences to conceptual ideas. Neither was there any focus on developing students' understanding of scientific inquiry procedures.

These are findings that echo the situation at any time in the history of school science (Hofstein & Kind, 2012). Basic elements of teachers' implementation of practical work seem not to have changed over the last century. As we claimed before, students still carry out recipe-type activities which are supposed to reflect science procedures and teach science knowledge, but which in general fails on both. This is not to say everything is the same. Science education has moved forward in the last decades and improved teachers' professional knowledge and classroom practice, but this improvement has not sufficiently caught up with the challenges of using laboratory work in an efficient and appropriate way. Teachers still do not perceive what is required to do so that the laboratory activities will serve as a principal means of enabling students to construct meaningful knowledge of science, and they do not engage students in laboratory activities in ways that are likely to promote the development of science concepts. In addition, many teachers do not perceive that helping students understand how scientific knowledge is developed and used in a scientific community is an especially important goal of laboratory activities for their students.

Ensuring that students' experiences in the laboratory are aligned with stated goals for learning demands that teachers explicitly link decisions regarding laboratory topics, activities, materials, and teaching strategies to desired outcomes for students' learning.

To sum-up, it is suggested that far more attention to the crucial roles of the teacher and other sources of guidance during laboratory activities is required, and researchers must also be diligent in examining the many variables that interact to influence the learning that occurs in the complex classroom laboratory.

The students' practice. The *National Science Education Standards* (NRC, 1996, p. 23) suggests that scientific inquiry "*… refers to the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world*." In the inquiry-type laboratory the students are provided with opportunities to be involved in the process of: Conceiving problems and scientific questions, defining controlling and manipulating variables in the experiment, measuring and observing, formulating hypotheses, predicting designing new experiments (aimed at accepting or rejecting the hypothesis), inferring, gathering and analysing data, and drawing conclusions about scientific problems or phenomena.

More specifically the NSTA (2004) in their declaration regarding teaching and learning by the inquiry method suggests that the teachers help students to:

– Learn how to identify and ask appropriate questions that can be answered through scientific investigations,
– Design and conduct investigations to collect the evidence needed to answer a variety of questions,
– Use appropriate equipment and tools to interpret and analyse data,
– Learn how to draw conclusions and think critically and logically to create explanations based on their evidence, and
– Communicate and defend their results to their peers and others.

Clearly, this would require a reorganisation of the laboratory from one which has traditionally been teacher centred to one that is more student centred. For this to work teachers need to focus on developing the following skills and abilities (Taitelbaum, Mamlok-Naaman, Carmeli, & Hofstein, 2008):

– Encouraging students to interact professionally, including sharing knowledge, with peers, community members, and experts,
– Helping students to solve problems, ask high-level questions, and hypothesise regarding unsolved experimental problems,
– Assessing students' progress continuously using a variety of alternative assessment methods that are aligned with the skills that the students develop, and
– Selecting the laboratory activities so that they are in alignment with the chemistry topic (concept) being taught, and make decisions regarding the level

of inquiry that is suitable to the students' cognitive abilities and also their interests.

The laboratory as a platform for developing learning skills

Identifying the laboratory as a platform for the development of learning skills is recognised in many reviews as well as research documents around the world (Lunetta et al., 2007; Hofstein & Kind, 2012). Trowbridge, Bybee, and Powel-Carlson (2004) listed the following domains of skills that laboratory activities have the potential, if used effectively, to develop in students:

- Acquisitive skills, such as: listening, observing, investigating, gathering data, and researching,
- Organisational skills such as: classifying, organising, outlining, and reviewing,
- Creative skills such as: planning ahead, designing a new problem and approach, inventing, and synthesising,
- Manipulative skills such as: using and handling instruments and materials, and constructing apparatus, and
- Communicative skills (i.e. working in small groups cooperatively).

Clearly, most of these skills can be developed (if time, appropriate conditions, and settings are provided) through inquiry-type laboratory experiences. In the turn of the century, the scope of skills was extended to include more general, high-order-type learning skills. Among these are: metacognition, argumentation, and asking relevant (scientifically sound) questions. These are skills that serve the student whilst still in formal education and also as a future citizen in a society that is highly influenced by science and its related technologies (see Chapter 1).

We shall describe briefly the theoretical background for each of these higher order learning skills. Later in this chapter we will demonstrate how such skills could be developed in the chemistry laboratory using an inquiry-type approach.

Asking relevant and scientifically oriented questions. Questioning ability is an integral part of meaningful learning and scientific inquiry. The formulation of a good question is a creative act and at the heart of what doing science is all about. Several studies noted the importance (and value) of questioning skills. For example, Zoller (1987), in the context of chemistry, stated that questioning is an important component in the real world, involving problem-solving and decision making processes. Similarly, Shepardson, and Pizzini (1991) regarded asking questions as an essential component of thinking skills for learning tasks and as a key stage in the problem-solving process. More recently, a comprehensive review was published by Chin and Osborne (2008) which surveyed the literature dealing with research on question-asking ability by students who learned science. They indicated the importance of providing a learning environment (e.g. the chemistry laboratory) that supports and fosters this ability among students who learn science, since science is a discovery discipline and discovery is achieved first by asking questions and then by conducting research in order to find the answers for that or any other questions. Chin and Osborne (2008) suggested that for students who learn science, their questions have the potential to (a) direct their learning and drive knowledge construction; (b) foster discussion and debate, thereby enhancing the quality of discourse and classroom talk; (c) help them to self-evaluate and monitor their understanding; and (d) increase their motivation and interest in a topic by arousing their epistemic curiosity. For teachers, students' questions raised in class and in the laboratory have the potential to (a) help the teacher evaluate students' understanding and tap into their thinking, thereby facilitating formative assessment and improving future teaching; (b) evaluate higher-order thinking; (c) stimulate further inquiry into the topic being studied via open investigations, problem-based learning, and project work; and (d) provoke critical reflection on classroom practice.

Developing metacognitive skills in the science laboratory. The definition of metacognitive is: "*knowing about knowing*." It can take many forms. Among others, it includes knowledge about when and how to use particular strategies for learning or for problem solving. It was suggested by Kuhn (1999) that metacognitive processes promote meaningful learning, or learning with understanding. By meaningful learning we mean that students improve their ability to apply what they have learned in a new context. One of the main characteristics of meaningful learning is the student's awareness of their physical and cognitive actions during the performance of a certain task. Also it should be noted that one of the goals of science education is the development of an independent learner (NRC, 1996). Efficient and independent learning requires the learner to be aware and in control of his/her knowledge and of the options to expand it. This means that the student must utilise and develop metacognitive skills.

White and Mitchell (1994) specify students' behaviours that, in their opinion, are characterised as "good learning behaviours" for students who developed certain metacognitive skills. A large part of these behaviours (and skills) are actions that constitute an integral part of the inquiry laboratory activity, such as; asking questions, checking work against instructions, correcting errors and omissions, justifying opinions, seeking reasons for aspects of current work, suggesting new activities and alternative procedures, and planning a general strategy before starting. Since the students that participate in the inquiry laboratory activities are encouraged to act according to the activities that are typical of students with developed metacognition, it is reasonable, we suggest, to assume, that during inquiry-based laboratory sessions students have the opportunity to practice and develop their metacognitive skills.

Scientific argumentation. When Driver et al. (2000) presented their introduction to argumentation in science education they pointed towards its relevance for practical work. They saw argumentation as correcting a misinterpretation of scientific method which has dominated much science teaching in general and practical work in particular. Rather than focusing on the stepwise series of actions carried out by scientists in experiments, they claimed that focus should be directed towards the epistemic practice involved when developing and evaluating scientific knowledge.

It is suggested that certain reasoning skills related to argumentation are domain general. That is people who are good at scientific argumentation are (a) able to think about a scientific theory, rather than just think with it, (b) able to encode and think about evidence in a similar way, and, in so doing, distance evidence from the theory, and (c) able to put aside their personal opinions about what is "right" and rather weigh the theoretical claim against the evidence.

Using argumentation is an effective way of developing an understanding of scientific ideas and, as such, students should be provided with suitable environment so that they can learn science by doing science. Small groups of students who conduct inquiry activities have the potential to provide a platform for students to participate in debate, supported or rejected by their argument. Furthermore, the skill of reasoning, which requires creating links between claims and evidence, can be developed.

In recent studies (Katchevich, Mamlok-Naaman, & Hofstein, 2010; Kind, Kind, Hofstein, & Wilson, 2011) analysis of the group discourse during both open-inquiry and confirmatory experiments revealed that there are differences in the nature and extent of the discourse. The discourse during inquiry experiments was found to be rich in arguments, whereas the one during confirmatory experiments was found to be sparse or lacked arguments altogether. It should be noted that the level and number of arguments posed is very much depended on the nature of the experiment conducted in which the students are engaged.

Different modes of instruction in the chemistry laboratory

The pedagogical literature regarding learning in the science laboratory (Trowbridge, Bybee, & Powel, 2004) suggests laboratory work, because it involves the individual directly in the learning process, e.g. minds-on and hands-on, as well as imparting learning skills offers advantages over other methods of instructional techniques often used in practical-type sessions. They suggested that (if planned properly and time was provided) students learn, in addition to the answer to the problem posed to them by the teacher or the laboratory guide, skills such as: manipulation, observation, and planning a new experiment. In general they learn science by doing science.

However, there are instances in which the teacher's demonstrations are also valuable. These are in cases that the:

- Equipment is scarce and expensive,
- Materials are expensive or hazardous,
- There are time consideration (shortage of time), or
- The teacher's goal for a certain experiment is to demonstrate certain apparatus or technique.

Clearly, if planned properly, a teacher's demonstration could serve as an effective alternative for students' hand-on activities regarding the development of skills such as observation, asking questions, and hypothesising.

It should be noted that the type of demonstrations used in the classroom are highly aligned with the teacher's goals and the skills that the teacher wants to impart in his/her students. In other words, there are several ways in which things (or phenomena) could be presented. The demonstration could be presented actively in which all the information related to the chemical experiments are given, e.g. the teacher details every part of the experiment (equipment, names of materials used, etc.). The only thing that the students do is to observe the chemical changes (e.g. change in colour or state of matter). The main goal is to verify information provided by the teacher previously. On the other hand demonstrations could be conducted by the teacher inductively in which the teacher while conducting the demonstration asks the students questions without providing answers. This type of demonstration could be part of a whole practical inquiry-type process (including asking questions, hypothesising and planning further experiment to verify or reject hypothesis). This type of demonstration is more student-centred and thus has potential to enhance student's motivation and interest.

Using ICT in the chemistry laboratory

In recent years in order to increase the effectiveness of the science laboratory ICT is embedded as an integral of the practical experiences (see Chapter 8). In the early 1980s digital technologies became increasingly visible in school laboratories and were recognised as important tools in school science (Lunetta, 1998). Thus, computer simulations could provide, in similar cases like demonstration, an effective replacement to students' own work in the laboratory. In addition to the above mentioned situations in which teacher's demonstration have advantage over hands-on activities one can add cases in which the chemical reaction is too fast or too slow. In using simulations one has to remember that simulation is a representation of the reality and thus, for some students (depends on their cognitive ability), this might cause another learning difficulty. Much evidence now documents that using appropriate technologies in the school laboratory can enhance learning of important scientific ideas. Inquiry empowering technologies (Hofstein & Lunetta, 2004) have been developed and adapted to assist students in gathering, organising, visualising, interpreting, and reporting data. Some teachers and students also use new technology tools to gather data from multiple trials and over long time intervals (Dori, Sasson, Kaberman, & Herscovitz, 2004). When teachers and students properly use inquiry empowering technologies to gather and to analyse data they have more time to observe, reflect, and construct conceptual knowledge that underlies their laboratory experiences. Using appropriate technology tools can enable students to conduct, interpret, and report more complete, accurate, and interesting investigations. Such tools can also provide media that support communication, student–student collaboration, the development of a community of inquirers in the laboratory-classroom and beyond, and the development of argumentation skills (Zembal-Saul, Munford, Crawford, Friedrichsen, & Land, 2002).

To sum-up, there is some evidence that integrating ICT tools in the science laboratory is promising. However, this development is still at its early stage. The level of which ICT is used in laboratory varies a lot. We assume that in the future this will expand. In addition, it is expected that ICT will cause more integration between practical work and computer-based simulation. This is an area that needs more research regarding its educational effectiveness. A more detailed discussion on the connection of ICT and the laboratory is provided in Chapter 8.

Problems that inhibit the effectiveness of practical work

Teaching chemistry effectively involves interplay between ideas and observations. Therefore an important role of practical work in chemistry is to help facilitate the development of links between observations and ideas (Figure 1).

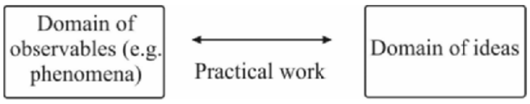

Figure 1. Practical work: linking two domains (Tiberghien, 2000)

But for this interplay to occur such ideas have to be introduced to students – and it seems reasonable that these ideas are 'in play' during the practical activity rather than being introduced only after it has been completed in order to account for what has been observed. Yet despite this, very few practical lessons are explicitly designed to generate such an interplay between observations and ideas during the practical activity (Abrahams & Millar, 2008). Even if these links were to be developed in subsequent lessons, the fact that the ideas are not available for the students to use in the lesson to enable them to make sense of the activity (to see its purpose) or of the observations made (to interpret these in the light of the theoretical framework of ideas and models) must inhibit the effectiveness of the practical work as a learning event in chemistry lessons. Indeed, Solomon (1999) discusses the critical role of 'envisionment' in practical work as a means of helping students to think about what might be going on 'beneath the observable surface,' i.e. linking scientific ideas/models with observations, as they undertake a practical activity. Such envisionment enables students to better comprehend their actions within a particular perspective on the event and in doing so helps to strengthen the 'minds-on' element of practical work.

To capture the sense that some activities, and the learning steps they are designed to help students take, make significantly greater cognitive demands than others, Leach and Scott (2002) have developed the concept of 'learning demand.' In the context of practical work there is a substantial difference between the learning demand of a task in which the primary aim is that students should see an event or phenomenon or become able to manipulate a piece of apparatus, and tasks in which the aim is to develop an understanding of certain theoretical ideas or models such as that used to understand the production and collection of ammonia in contrast to the production and collection of carbon dioxide. (Note: By understanding that ammonia is very soluble in water whilst carbon dioxide is only soluble in small quantities it is possible to appreciate why the collection of these two gases must use different techniques.)

The principal implications here for improving the effectiveness of practical work in chemistry is that there is a need to increase teachers' awareness regarding practical tasks. In other words they need to be more aware that practical tasks requiring students to make links between the domain of objects and the domain of ideas are appreciably more demanding than those that simply require them to observe and remember the observable features of an event or process. Task design needs to reflect the fact that simply 'doing' things with apparatus and chemicals will not lead to students 'learning' (or even 'using') scientific ideas and concepts unless they are provided with what Wood, Bruner, and Ross term a 'scaffold' (1976).

The process of scaffolding initially provides the means by which students are helped to 'see' the phenomena in the same 'scientific way' that the teacher 'sees' it (Ogborn, Kress, Martins, & McGillicuddy, 1996). As Lunetta (1998) has argued, laboratory inquiry alone is not sufficient to enable students to construct the complex conceptual understandings of the contemporary scientific community. He wrote that: "*If students' understandings are to be changed towards those of accepted science, then intervention and negotiation with an authority, usually a teacher, is essential*" (p. 252). The issue then raises is what form this intervention and negotiation with the teacher takes, and the extent to which the teacher recognizes this and explicitly builds it into the practical task.

Certainly, if teachers' lesson plans include objectives that relate to learning about ideas it is important that they make explicit precisely how they intend their learners to learn about ideas. Indeed, although practical work is frequently seen by many teachers as a means of simultaneously achieving a broad range of learning objectives, its effectiveness can be significantly enhanced if it is used to achieve a relatively small number of clearly and explicitly stated learning objectives.

Given the limited time available in most practical lessons, and the importance of ensuring that the students are able to do what the teacher intends with objects and materials, the widespread use of 'recipe style' tasks is likely to continue to play a significant part in many chemistry practical lessons. However, if the scale of the cognitive challenge for students, in linking their actions and observations to a framework of ideas, were recognised, secondary teachers might, as many of their primary colleagues already do (Abrahams & Reiss, 2010), divide practical lesson time more equitably between doing and learning. In this respect it appears that whilst the underlying epistemological flaws associated with an inductive, discovery-based view of learning have long been recognised (Driver, 1975) many teachers continue to adopt such an approach (Abrahams & Millar 2008). Indeed, in many cases teachers seem to expect that the ideas that they want their students to learn will simply 'emerge' of their own accord from the observations or measurements, provided only that the students are able to produce them. And it is for this reason that they focus their teaching on ensuring that their students are able to produce the phenomena. Yet despite the emphasis that many teachers place on the successful production of the phenomena Abrahams and Millar (2008) have found that very few of the students that they interviewed were able to recollect scientific ideas and/or concepts relating to practical work that they had previously carried out. Despite their having successfully produced the phenomena almost all of the students' recollections were descriptive accounts, with little scientific content, of what they had done and/or seen with objects, materials and phenomena.

We are *not* suggesting that 'doing' and 'learning' need to be rigidly separated, but rather that teachers need to devote a greater proportion of the lesson time to helping students use ideas associated with the phenomena they have produced, rather than seeing the successful production of the phenomenon as an end in itself.

Research on the effects of the inquiry laboratory

The higher order learning skills (i.e. inquiry skills) that can potentially be learned in the science laboratory can be divided into two sets of objectives categories. The first set of objectives, which can be attained only through hands-on experiences provided in the laboratory, such as; observing, conducting an experiment, and manipulating materials and equipment (Lazarowitz & Tamir, 1994; Lunetta et al., 2007). The second set of skills are those related to science teaching and learning in general namely: enhancing students' motivation to learn science, learning scientific concepts, developing independent learners, and enhancing self-regulated learning. In conducting inquiry-type practical activities the students can develop inquiry skills such as asking questions, formulating hypotheses, and planning a controlled experiment. In addition, in recent years (as mentioned above) the students should be promoted to develop skills such as argumentation and metacognition. If planned properly and aligned to the topics and concept taught, the unique laboratory environment, provides the student with a "learning in context" situation.

Well planned and designed chemistry-based laboratories can provide the learner with an authentic and contextualised learning environment in which all the inquiry skills and abilities can be developed (Tobin, 1990; Lazarowitz & Tamir, 1994; Hofstein et al., 2004). Based on their review of the science laboratory literature, Lazarowitz and Tamir (1994) indicated that the potential of the laboratory as a medium for teaching science is enormous. More specifically, they wrote that the laboratory is the only place in school where certain kinds of skills and understandings can be developed. In general, in the traditional laboratory, in which most of the experiments are confirmatory in nature, the students perform the experiments according to specific instructions provided by the teacher or the laboratory guide. The laboratory guide provides students with step-by-step instructions that they have to follow. Very often these are highly focussed on manipulative skills in which the student is required to manipulate equipment and materials. In the inquiry laboratory, on the other hand, the students are provided with a lot of opportunities (and time) to develop almost all the inquiry skills as well as higher order thinking skills, e.g., asking questions, hypothesising, and developing metacognitive skills (Kipnis & Hofstein, 2008).

In various studies, it was found that in all the inquiry variables that were assessed, the experimental (inquiry) group significantly outperformed the comparison group. More specifically, the students in the experimental group were found to be better observers (they recorded 65% of the total number of potential observations that can be observed). Conducting and recording observations in the context of practical work is an important stage in the scientific investigation process. In addition, the students in the experimental group asked significantly more high-level questions related to the experimental phenomena. Note, that asking questions is an important activity that is central to scientific research (Chin & Osborne, 2008), and the literature suggests that this is an essential step in the process of solving scientific problems (Dori & Herscovitz, 1999; Chin & Osborne, 2008).

The students in the inquiry group were able to select more thoughtful questions for further investigations compared with the comparison group. Finally, they managed to select a better experimental strategy (planning an experiment) for accepting or rejecting their scientific hypothesis. These activities are somewhat aligned with the claim made by Krajcik, Mamlok, and Hug (2001), who suggested that students who perform the various phases of inquiry are challenged by asking appropriate questions, finding and synthesising information, monitoring scientific information, designing investigations, and drawing conclusions.

A vision of contemporary laboratory work in chemistry education

We operate in an era in which the development of high order thinking skills is regarded as important as the development of scientific concepts (Zohar & Dori, 2003). In many countries around the world, achieving scientific literacy for all students has become a central goal for education (see Chapter 1). The target population is not only those who eventually embark on a career in the sciences but also all those who will become future citizens. Scientifically literate citizens should have knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. In addition, they should possess specific types of scientific abilities and skills. Also, scientifically literate citizens should be able to ask, find, or determine answers to questions derived from curiosity about everyday scientifically-based experiences. They should have the ability to describe, explain, and predict natural phenomena. In addition, they should also be able to read articles about science in the popular press and to engage in conversation about the validity of the content, applications, and conclusions. This should be done on the basis of understanding scientific phenomena and on the basis of a critical approach. Scientifically literate citizens should be able to evaluate the quality of scientific information on the basis of its source and the methods used to obtain the information. They should also be able to pose and accept arguments based on evidence and can draw appropriate conclusions from such arguments. It is suggested, that one of the main goals of science education is to develop these abilities and skills. It proofed that the inquiry laboratory activities constitute an appropriate learning environment for attaining this goal. At the beginning of the inquiry laboratory, after observing a particular phenomenon, the students practice the skills of asking questions. Thereafter, they choose, (among the questions that they cannot answer) a question for further investigations and they attempt to formulate a hypothesis regarding the inquiry question. When the students plan the experiment in order to verify their hypothesis, and when they analyse their results, they have to evaluate the quality of the scientific information and the methods used to generate it. During the group activity, when students interact with their peers and with the teacher, they use argumentation skills. When they write their final report, they use their ability to assess the validity of the results and their ability to draw conclusions. To sum up, development of inquiry skills should be seen as an important component of scientific literacy and should not be overlooked. Such practice should be more widely implemented into the chemistry classrooms worldwide.

THE PRACTICE OF CHEMISTRY TEACHING

Two different approaches to teaching the same thing

Consider how two illustrative teachers of regular 11th grade chemistry classes teach the topic 'acids and bases.' Two teachers, Sarah and David, are planning laboratory activities dealing with the reaction of acid with carbonate salt (a reaction that releases carbon dioxide gas).

Sarah's class. Students enter the classroom. Each group of three students sits down and on the table in front of each group there is a tray with equipment and materials. Every group has a piece of paper with instructions:

> *The goal of the task: to understand the reaction between acid and carbonate ions.*
>
> *Background: When carbonate salt reacts with an acid, the following reaction occurs:*
>
> $$2H_3O^+_{(aq)} + CO_3^{2-} \rightarrow CO_{2(g)} + 3H_2O_{(l)}$$
>
> *When the acid reacts with bicarbonate ion, the reaction is:*
>
> $$H_3O^+_{(aq)} + HCO_3^- \rightarrow CO_{2(g)} + 2H_2O_{(l)}$$
>
> *In the tray in front of you, you will find various salts and different acids. You should react each of the acids with each of the salts and record the observations on the attached table.*
>
> *Conclusion: Write full formulations of all the reactions that occurred.*

During the lesson, the students follow the instructions and perform the experiment. In the plan they are told clearly how to check every acid with each salt, they make observations, they record their observations and they use their knowledge in chemistry to formulate chemical equations that describe the reactions that occurred. When they next hear or read about a reaction between an acid and carbonate ions, it might be expected that they will draw on their recollections of this experiment in order to remember how such a reaction occurs.

David's class. Students enter the classroom. Each group of three students sits down and on the table in front of each group there is a tray with equipment and materials. Every group has a piece of paper with instructions:

Experiment instructions:

Put in the plastic bag 10 grams of powder A[1]*, add 10 ml of water and mix well. Carefully put in the same bag a small plastic vessel with 7 grams of powder B*[1]*. Remove the air from the bag and close it tightly with a rubber band. Be careful not to spill the solid into the vessel while you are closing the bag. Pour the contents of the vessel into the fluid that is in the bag and mix well.*

Record all your observations.

Write down questions that arise during the experiment.

Choose one of the questions you asked and formulate it as a research question.

Assume the answer to this question. Explain your hypothesis by using rigorous scientific knowledge.

Plan an experiment in which you can confirm or refute your hypothesis. Specify all the stages of the experiment.

Write down the materials and equipment you need to perform this experiment.

Following the teacher's approval, give the laboratory assistant the order form for the equipment and materials.

[1] A is citric acid
[1] B is sodium bicarbonate

The students begin to perform the experiment and follow the instructions. When they observe the bag expanding after mixing all the materials in it, they become excited, and they begin to wonder: What happened? Why did the bag expand? What was this reaction? When they continue, following the instructions and doing all the tasks that they are requested to do; they practice many skills that cannot be learned in the regular lessons. Besides making and recording observations, the students ask many questions about the phenomenon they observe; they formulate an inquiry question and predict a hypothesis about the answer to this question, basing their hypothesis on scientific knowledge. Next, they plan an experiment in order to confirm or reject their hypothesis, perform the experiment that they planned, indicate the results, draw conclusions regarding those results, and finally indicate the results regarding their hypothesis.

These two classes represent two different approaches of instruction for practical work: a traditional confirmatory laboratory using 'recipe' style instructions in Sarah's class and an inquiry laboratory in David's class. The two approaches differ in terms of:

– The role of the student and teacher,
– Skills that are used and developed during the activity,
– Open-endedness, and also that
– Inquiry-type activities are very often more time consuming compared to the confirmatory activities.

It should be recognised that these two approaches are opposite ends of a continuum of practice in which teachers are able to draw on features from both when constructing their lessons and, as such, there are many variations of laboratory work.

Analysing the role of the students and teacher in the laboratory

In the traditional confirmatory laboratory all the activities are organised by the teacher. The teacher plans the experiment, the teacher is the one that usually poses the questions during the lesson and gives detailed procedural instructions regarding the activity. In contrast, the inquiry laboratory is student centred. In such a laboratory the students ask the questions, they plan the experiment, and they control their activities during the laboratory class. When conducting a discovery experiment, the students perform the experiment according to the teacher's instructions, and they gather the data but decide upon their own conclusions. A laboratory activity can be classified according to the division of responsibility between the students and their teacher. Based on the teacher's aim and/or objectives teachers can retain or transfer responsibility of some or all of the elements relating to an experiment to the students. Table 2 provides a useful tool for aligning the practical activity to the needs and characteristics of each particular class.

Table 2. Allocation of responsibility in laboratory tasks (based on Herron, 1971)

Who is responsible for the following elements of a practical lesson?	Teacher	Student	Joint
Statement of problem			
Hypothesis			
Working plan			
Performance			
Data gathering			
Conclusion			

Understanding skills development in laboratory lesson

In our example above, in Sarah's class, when the students studied using 'recipe' style instructions, they read the instructions. They had to understand them in order to follow the instructions. They had to manipulate materials and equipment according to the instructions, in order to answer the generally, low-level type questions that were asked by the teacher, and to document their work as requested by the teacher. In order to answer those questions, the students have to use low-level thinking skills according to Bloom's taxonomy – knowledge and comprehension (see Chapter 2). Usually, this activity is done in groups and the students are given an opportunity to practice certain social skills such as argumentation. In addition, they can also be encouraged to communicate and cooperate with their group mates, in order to successfully accomplish the task in the time allocated by the teacher.

In contrast, in the first phase of the experiment in David's class, when the students were experiencing the inquiry laboratory, they had to follow a very brief traditional 'recipe' style set of instructions. However, in the second phase the teacher transfers certain responsibilities across to the students in so far as the students now have to plan how to record all their observations and distinguish between observation and interpretation. Following the observations students are encouraged to ask as many low-level and high level questions related to the phenomena that they observed.

In an inquiry-based class (e.g. David's class) the next step will be to choose and formulate an inquiry question, to formulate a hypothesis about the answer to this question, and to justify the hypothesis by using relevant scientific knowledge. In this part of the activity the students are required to use their chemistry knowledge, and to use thinking skills involving analysis and synthesis in order to formulate an appropriate hypothesis. In the last part of the laboratory activity, the students prepare a report in which they relate to the conclusion of their experiment regarding the inquiry question and hypothesis. They are asked to relate to the reliability and validity of their results. This part of the activity requires high-order thinking skills: analysis and synthesis.

There is also a difference between the types of laboratories concerning the opportunity to use and to develop metacognitive skills. Baird and White (1996) claimed that:

> If carried out thoughtfully, the process of inquiry will generate a desirable level of metacognition; the person will know about effective learning strategies and requirements, and will be aware of, and be capable of exerting control over, the nature and progress of the current learning task. (p. 191)

They also claimed that four conditions are necessary in order to induce the personal development entailed in directing purposeful inquiry: time, opportunity, guidance, and support. In David's class, where the inquiry laboratory activity took place, the students get the time and the opportunity to practice their metacognitive skills, and the teacher gives them the guidance and the support that they need. Thus, one can conclude that the inquiry laboratory activity is especially suitable for enhancing metacognition and meaningful learning. The reason for this is that during the activity the students perform an open inquiry, which integrates strategies that are known in the literature (White & Mitchell, 1994) as metacognition promoters: working in small groups, having time for group discussions, observing

Table 3. Examples of discourse segments that represent metacognition components during the inquiry laboratory activity

The student's quotation	***Our interpretation***	***The metacognition component that is represented***
"… it reminds me of a function of … a logarithmic one …."	The student remembers knowledge that had been acquired in the mathematic lessons. This indicates the existence of the student's knowledge about his own knowledge.	the student's *metacognitive* declarative knowledge about himself
"What about waiting time?"	The student understands that his partner's thoughts differ from his own and therefore she suggests a question that she had not thought about.	the student's *metacognitive* declarative knowledge about others
"You need something …. Think about a graph, something that you can represent with a graph."	The student explains that she suggests this particular question because of the type of answer. She understands that the inquiry process has to lead to conclusions about the phenomenon; therefore, she searches for a suitable question that enables her to represent the results in a graphic way that helps to arrive at conclusions.	the student's *metacognitive* procedural knowledge
Gal: "Listen to me; it reminds me of a function of …." Liran: "Sure, a quadratic function."	The students use their knowledge of mathematical functions to describe the dependence between the variants in the experiment. They know how to use the appropriate strategy in spite that it was learned in an entirely different context.	the student's *metacognitive* conditional knowledge
"We want the gas to stay. So, maybe we will cool it? We do not need heating; we need ice and another big bowl for cooling …."	The student suggests another plan for the experiment.	the planning component concerned with regulation of cognition
"… But the gas pressure has an influence too. … I think we should start from the beginning."	At each stage of the experiment the students examine the results of their observations in order to decide whether they are logical.	the monitoring and evaluating components of the regulation of cognition

phenomena that should be explained at the particle level, and exploring questions that were asked by the students. In Table 3 there are few examples that demonstrate the use of metacognitive skills by the students during the discourse that is done during the activity of the inquiry laboratory.

Organizing the work in the laboratory classroom

There are different ways of organising laboratory work in a chemistry laboratory classroom. The most common organisational structures are the demonstration and the experiment conducted cooperatively or individually by the students. The advantages of a demonstration is that the teacher is able to explain step by step the experiment, the purpose of each single activity and that he can focus students' attention towards the observations. On the other hand, in general, a demonstration makes the students passive recipients of information and thus only rarely they are engaged in cognitive challenges.

Doing experiments in parallel groups has the advantage making the students themselves become the active learners. But as it was discussed earlier in this chapter, such engagement only goes beyond physical activity, if the experiment allows for and challenges students' freedom of thought, i.e. through inquiry. Just following a prescribed recipe (in confirmatory-type experiments) may lead to physical activity. But, moving to inquiry and open laboratory tasks also activates students thought. Difficulties in conducting experiments in parallel groups often conducted in cases in which, the amount of material and equipment are scarce so that the experiment can only be done few times. It should be noted that in cases in which the experiment is very complex inexperienced groups of learners might find the experiment too demanding and thus difficult to perform on their own. Such experiments deserve adequate and precise, preparations by the teacher and/or the laboratory assistant. This might ensure that the students will be able to get to the right solutions and experimental observations.

Aside from these two very classical ways of conducting experiments in class, the field of cooperative learning allows for other forms (see Chapter 7). One of these methods is explained as an example using a case on teaching about biodiesel: the learning at stations mode (Eilks, 2000, 2002). The learning at stations-laboratory offers different places within the classroom where different activities are prepared for the students. Figure 2 gives an overview regarding different stations on the example of biodiesel.

The learning at stations mode allows the students to work on the stations in a sequence that they decide upon. Within a given timeframe they are free to dedicate different amounts of time to each of the stations. It is up to the teacher to give rules as to which of the stations are mandatory, and from which the students are free to choose. This combination of compulsory and optional tasks allows the teacher to vary the laboratory classroom learning environment in which less experienced groups of students can be provided with more support and guidance. More experienced groups are able to follow their own path of learning, allowing them to experience the creation of self-discovered and networked knowledge.

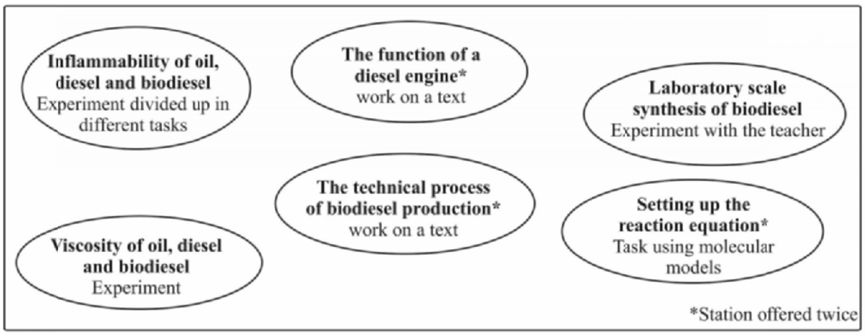

Figure 2. Learning at station on the example of Biodiesel

The assessment of the students' achievement and progress in the chemistry laboratory

The chemistry laboratory offers a unique mode of learning and teaching and therefore a unique mode of assessment is required for students in the laboratory. Because the students use and develop certain skills in the laboratory, those skills have to be assessed. We recommend a continuing assessment that evaluates the students' progress and takes into consideration all the skills that are expressed during the laboratory activity.

Table 4. Assessment criteria for laboratory work

Criteria	***Suggested weighting***	***Specific skills and actions***
Conducting the experiment	15%	Following instructions Manual dexterity
Observing	10%	Observations Recording observation
Inquiry	35%	Questioning Hypothesising Planning
Conclusions	20%	Presenting results Drawing conclusions Criticism and summary
Communication	10%	Oral presentations
Social skills	10%	Cooperation in groups

For example, in order to assess students' achievement and progress while performing the experiments, two assessment tools were developed. The assessment tools combine the student group's assessment tool – a 'hot report' (Hofstein et al., 2004) and the teacher's observations of the individuals in each group. In the observational techniques the teacher observes the students unobtrusively regarding their involvement in the group activities in the inquiry laboratory related exercise. The 'hot report' is the group's product and is prepared in the laboratory during or immediately after the laboratory exercise. The criteria for assessing the 'hot report' are summarised in Table 4.

All the components of the students' assessment (regarding their achievement and progress) are accumulated in a personal portfolio. This is eventually used to assess students' achievement as part of their final grades. Also Di Fuccia, Witteck, Markic, and Eilks (2012) recently suggested some alternative assessment with the goal in mind to provide new techniques for assessing students' achievement in the laboratory.

SUMMARY: KEY SENTENCES

– The science laboratory is a unique learning environment related to instruction, learning, and assessment.
– The chemistry laboratory can be presented to the learners as inquiry, confirmatory, or discovery approaches.
– The chemistry laboratory could be organised and conducted as teacher demonstration, students' individual experimentation, collaborative project, or problem-solving activity (with or without support from ICT).
– If designed properly the chemistry laboratory has the potential to provide an effective platform for the development of high order learning skills (such as: inquiry skills, argumentation, metacognition, and asking questions).
– The science (chemistry) laboratory can, if planned properly and in an open or inquiry style, provide opportunities for a good blend of minds-on and hand-on activities, i.e. learning science by doing science.

ASK YOURSELF

1. Make a list: What are the specific aims for the inclusion laboratory work in the chemistry classroom?
2. Explain: What is meant by inquiry-type laboratory work? What makes it different from traditional practices of doing experiments in chemistry classes?
3. Make a list of skills that can be promoted through inquiry-type laboratory activities in chemistry education.
4. You have candles of different sizes, a variety of beakers and bowls, and a lighter. Create an inquiry-activity for lower secondary chemistry students.
5. Think about the topic of alcohols. Suggest learning at stations laboratory for this topic. Which stations/activities might be offered to the students?

HINTS FOR FURTHER READING

Abrahams, I. (2011). *Practical work in secondary science: A minds-on approach*. London: Continuum. This is a comprehensive guide to the theory and practice of teaching minds-on practical work in secondary science. The book provides guidance to the implementation of practical work in science laboratories. In addition the book provides a compelling analysis of how practical work should be at the heart of school science.

Lunetta, V. N., Hofstein, A., & Clough, M. P. (2007). Learning and teaching in the school science laboratory: An analysis of research, theory, and practice. In S. K. Abell & N. G. Lederman (eds.), *Handbook of research on science education* (pp. 393-442). Hilsdale: Lawrence Erlbaum. This handbook chapter reviews the research on the laboratory work accumulated over more than 50 years. Teachers and professional development providers who are interested in the area of effectiveness of practical/laboratory work might find interesting insights as well as research methods used in this area.

Hofstein, A., & Kind, P. (2012). Learning in and from science laboratories. In B, Fraser, K. Tobin & K. McRobbie (eds.), *International handbook on science education* (pp. 189-207). Dordrecht: Springer. This is a comprehensive review of the literature regarding theory and practice of laboratory work.

Trowbridge, L. S., Bybee, R. W., & Powel-Carlson, J. (2004). *Teaching secondary school science* (chapter 14, pp. 195-207), Columbus: Merill Prentice Hall (8^{th} Edition). This chapter deals with several issues related to teacher's demonstrations vs. student individual work in the science laboratory. This is very practical chapter aimed at secondary school teachers.

Allen, M. (ed.) (2012). Special issue "Practical work." *Eurasia Journal of Science, Mathematics and Technology Education, 8*(1), 1-72. This special issue describes selected aspects and contemporary trends of learning in the laboratory from six different countries.

RESOURCES FROM THE INTERNET

NSTA (National Science Teachers Association) Declaration: www.nsta.org/about/positions/inquiry.aspx. This is a link to the NSTA declaration related to teaching science by inquiry, teachers' and students' role and activities.

R. Millar: Teaching and learning science through practical work: nordlab.emu.dk/pub/pdf/BidragRobinMillar.pdf. This important paper discusses the state of the art in learning on the lab.

ASE (Association for Science Education): www.schoolscience.co.uk/teacher_zone/view_resources/listing.cfm?FaArea1=customWidgets.contentItem_show_1&cit

_id=4578&subject_id=4797. The ASE is leading a consortium of science education specialist organizations in a project aimed at improving the quality of practical work taught in schools in all levels.

ACS (American Chemical Society) laboratory safety information: www.sciencebuddies.org/science-fair-projects/project_ideas/Chem_Safety.shtml. This is a link to the ACS safety URL. It includes special section for teachers and links to other safety resources and guides.

Student Active Learning in Science (SALIS): www.salislab.org. This EU-funded project offers a guide and collection of examples for low cost equipment, experiments, and student active learning pedagogies.

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7. HOW TO ORGANISE THE CHEMISTRY CLASSROOM IN A STUDENT-ACTIVE MODE

Everyday, chemistry teachers all over the world are challenged by the question: Should I explain the chemistry content in a frontal mode using the blackboard, or am I able to apply methods to activate the students learning on their own terms? This chapter is based on the premise that learning processes should be based as much as possible on student-centred activities (hands-on and minds-on). A justification for more thorough student-active learning in the chemistry classroom is derived from the theory of social constructivism. Evidence for the positive effects of more student-active classrooms and cooperative learning will be discussed. This discussion will be illustrated by examples from chemistry education regarding how to activate students' thinking, to engage them into a cooperative mode of learning, or to use e.g. drama and role-play in the chemistry classroom.

THEORETICAL BASIS

> *Most people tire of a lecture in ten minutes; clever people can do it in five. Sensible people never go to lectures at all.*
> (Stephen Leacock in 'Discovery of England,' 1922, as cited in Byers & Eilks, 2009, p. 5)

From teacher-centred teaching to student-centred learning

The pedagogy of teaching secondary chemistry in many classrooms all over the world is still dominated by a teacher-centred approach. The teacher is explaining the content, is presenting experiments, and interaction with students is limited to brief periods of questions and answers. Thus, teaching is often not more than lecturing with short phases of individual tasks or guided bilateral interactions between the student and the teacher. The learning theory behind this approach is little more than a simple process of information transfer or as Byers and Eilks (2009) called it the 'Passive Diffusion Model of Knowledge Transfer.'

It is this teacher-centred practice that involves the teacher pouring information over the students and all the students are required to do is to absorb it (Figure 1). As a result, when teachers evaluate examination tests they discover all too often that what they thought they had taught, and what their students had actually

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learned, are very different. Their reaction is to try to explain better. They try looking for that little bit of magic that will enable their knowledge to be transferred over to their students. The teachers hope that the better they present the content the better their students will learn (Byers & Eilks, 2009).

But, it is not only the fact that teachers are not always able to explain everything to others in a sufficiently comprehensible fashion. It is also that the students often fail to listen or follow direction with sufficient care and attention. Sometimes they even lack the necessary cognitive abilities or prior knowledge to allow for instant understanding of the newly acquired information (see Chapter 4). The underlying problem is deeper. The problem is that learning is much more complex than merely listening, memorising and repeating (Bodner, 1986). From research, we know for a long time now (e.g. Peterson & Peterson, 1959) that most information obtained simply by listening is forgotten very quickly, with only a small percentage ever reaching the long term memory.

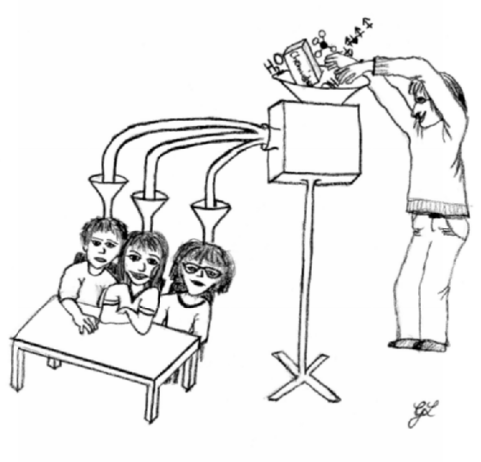


Figure 1. The 'Nuremberg Funnel' – An illustration of the belief that learning of chemistry is a simple transmission of content

Educational theory suggests that, although we might wish otherwise, knowledge cannot be transferred intact from the mind of one person into the mind of another (Bodner, 1986). Information may be presented, but meaning and understanding can only be constructed by the mind of each individual learner (Wittrock, 1989). Meaningful learning is the active integration of new information with knowledge already possessed by the learner. The subsequent interpretation of this new information will then depend heavily on what the learner already knows and what cognitive processes will occur in the mind of the learner (see Chapter 4).

This means that the quality of teaching should not be assessed in terms of the effort being put in by the teacher. The quantity and particularly the quality of learning is surely much more dependent on the effort being put in by the learner. It is quite a bit ironic. All too often when the teacher increases input to try to address learning difficulties being experienced by students, the students start to reduce their own efforts. Teaching should apply a converse approach. Teaching chemistry will become more efficient at the point where we apply methods where students become more active, hands-on and minds-on.

From behaviourism to social constructivism

The style of teacher-centred teaching and the Passive Diffusion Model of Knowledge Transfer as described above are based in the theory of behaviourism, which was the dominant educational theory during the first half of the last century. Behaviourism interprets every human action (action, thinking, feeling, etc.) in terms of 'behaviour' (Skinner, 1976; Mills, 2000). According to the behaviouristic theory, every action is considered simply as a response to a stimulus; if the correct stimulus is provided the required behaviour will inevitably follow. Behaviourism stems from experiments with animals, e.g. Pavlovs well known experiment with the dog. From behaviourism, one can train an animal, or a human, provided one can identify a stimulus necessary to promote the desired response. In terms of learning a teacher wishes a student to learn something by simply providing the right stimulus, e.g. presenting the right pieces of information, in the right sequence, at the right moment.

Although the theory of behaviourism has been developed over time to account for a range of observations (Mills, 2000), in its principle it remained the same. It is suggested that giving the correct information to a student, will enable him to (a) store this information in his/her memory, (b) assign the intended meaning to this information, and (c) have this information readily available for future use. Unfortunately, evidence from educational research suggests, that none of the above three expectations is justified. Peterson and Peterson (1959) showed that about 85% of the information entering the short time memory is no longer available to a learner a mere 15 seconds later, if it has not been connected to any constructed meaning, or if no any additional stimuli are given to support memorisation in the meantime. While behaviourism can certainly be helpful in understanding the simple issues associated with basic training processes, like memorisation of facts or training simple psychomotoric skills, it has proved much less successful when it comes to comprehending the important issues of learning with understanding.

Today's understanding of effective learning of chemistry is highly based on the theory of constructivism (Bodner, 1986). Among other issues, constructivism suggests that science teaching should apply teaching methods making the learner the active player in their own learning process. Such methods should seek to encourage the learner to become cognitively engaged in developing understanding of the topic being taught. The more elaborated interpretations of constructivism not only seek to make students active thinkers, but to promote interaction between them. One of these elaborated interpretations is the socio-constructivist perspective on learning attributed to the Russian psychologist Lev Vygotsky (Hodson & Hodson, 1998).

One of the central ideas in the works of Vygotsky (1978) is the role of interpersonal communication and social interaction for learning. From this point of view, sustainable learning does not take place via the contemplation of content by an individual learner but by a process that mainly functions through cultural and social mediation about content (Driver & Oldham, 1986). Construction of meaning is understood as a process of negotiation in discussions with others. With a quote from Lazarowitz and Hertz-Lazarowitz (1998, p. 451) the social component of constructivist learning is described as:

> … cognitive construction is facilitated through the following activities, all of which are based on peer-interaction: students present their own ideas by explaining them to other group members; they think and talk about their experiences; they suggest and try out new ideas; they reflect on changes in their ideas; they negotiate and aid other students to clarify their thoughts; and they move ideas forward by making sense of new ones. Indeed, constructivist theory brings to light the significance of social-cognitive interaction, cooperation and collaboration to the science teaching-learning context.

This view on learning makes interaction between the student and the teacher, and also among the students between themselves important features for promoting effective learning in general and in learning chemistry in particular. Because interaction is mainly done through language considering linguistic issues for effective learning processes becomes an important issue too (see Chapter 5).

Cooperative learning to promote student-active learning

From the theory of social constructivism we know that chemistry education should apply methods fostering student activity and make learning a cooperative experience. Cooperative learning is an advanced mode of learning in groups. Lazarowitz and Hertz-Lazarowitz (1998, p. 449) describe the difference:

> Cooperative Learning brings to the school a different learning organisation in which the classroom is structured into cooperative teams of learners, thus making learning together a way of life. Students tutor each other, conduct group projects, practice mutual assistance by sharing and exchanging information, and create a collaborative-cooperative learning environment.

Far more than a mere exchange of ideas can take place in such cooperative learning environments. Instead of studying the mental content of individual minds, cooperative learning focuses on the processes of interaction, participation, discourse, and negotiation. Cooperative learning leads to co-constructing knowledge and to building up collaborative knowledge where the group is able to attain a level of understanding that could not have been achieved through the mental processing of any one individual from within the group alone (Johnson & Johnson, 1999).

Nevertheless, it is well known that merely putting students into a group does not necessarily lead to effective learning. The effective working of a group is often disrupted by a lack of structure within the group and differing interests among the group members (Johnson & Johnson, 1999). Thus, it is important that the group should have a clear structure, and sometimes it may even be preferable to leave it up to the students themselves to agree on the structure to be adopted. A lot of research on cooperative learning in general and in science education in particular is available today. The evidence gained from this can help to understand which factors must be fostered to enhance students' learning by high quality student cooperation (e.g. reviewed in Lazarowitz & Hertz-Lazarowitz, 1998; Johnson & Johnson, 1999).

The literature, in particular the five quality criteria for functioning cooperative learning as proposed by Johnson and Johnson (1999) has given us a useful and well-established basis for reflecting upon cooperative learning:

– *Positive interdependence*: Each member of the class understands and values the benefit of working together to achieve a common goal. The effort of each group member is required and is indispensable for the group's success and everyone has a unique contribution to make the group's task a success.
– *Face-to-face promotive interaction*: The students encourage and facilitate the other's efforts to complete their tasks in order to reach the common goals. Students providing each other with help and assistance. They exchange resources, such as information or materials, and process information efficiently by providing each other with feedback.
– *Individual accountability/personal responsibility*: The performance of each individual student is assessed and the results are given back to the individual and the group. All students are responsible for their group mates but also for themselves to contribute to the group's success.
– *Interpersonal and small group skills*: Students are able to or learn to trust and interact with each other, communicate accurately and unambiguously, accept and support each other, and resolve conflicts constructively.
– *Group processing*: A reflection on how well the group work functioned in an explicit and structured process. Reflection should include what member actions were helpful and unhelpful, and what actions should be continued or changed.

If these criteria for cooperative learning are considered and used, the classroom environment has high potential for effective learning, student motivation, and the development of skills beyond the learning of chemistry topics and theories. Such non-cognitive skills include team working abilities, organising and structuring of projects, and negotiating of consensus following conflict within the group. The use of cooperative learning activities has been found to result in higher cognitive achievement, better development of higher-level thinking skills, increased student self-confidence and satisfaction, and better attitudes towards subject matter (Lazarowitz & Hertz-Lazarowitz, 1998).

In the literature, several basic modes of cooperative learning are described. The basic models differ in their structure and the levels of guidance given to the students, who work in small groups. Some of the basic models are discussed below. In addition to the basic models of cooperative learning detailed below, there is also a wide variety of cooperative teaching techniques (Sharan, 2004). Some of these are also illustrated by examples from the chemistry classroom within the practice section of this chapter, e.g. how to introduce atomic structure within a cooperative learning scenario in secondary chemistry classes (Eilks & Leerhoff, 2001).

Group investigation. Group investigation (GI) based on the work by Sharan and Hertz-Lazarowitz (1980) is a model for conducting joint projects within a class (see also "*The Project Method*" by Frey, 1982). GI consists of six steps. In the beginning the whole class considers a joint project and then determines appropriate sub-topics. The class is split into sub-groups of 4-6 students each. Each sub-group plans their investigations for their part of the project. The planned activity is carried out as a group in the laboratory while the process is supported by a variety of resources which can be searched and analysed by the students working independently within their groups. The teacher acts as a mentor, convener and collaborator for the students' investigation. At the end, each group gives a presentation, poster, report or some other contribution to the whole class to bring the sub-topics back together. Finally, the results are assessed by the students and teachers.

Student teams and achievement divisions and teams games tournament. Student teams and achievement divisions (STAD) by Slavin (1978) and teams games tournament (TGT) by De Vries and Slavin (1978) use competition between groups as a framework to support cooperative learning. In STAD, for example, the class is assigned a specific set of information to be learned. Heterogeneous small groups of 4-6 students are formed. The joint aim is that students start learning as a team in order to prepare each other to be individually successful in a quiz, test or game. At the end everyone has to participate in the test individually. However, it is not only the student's individual score that is registered. The students' scores are also aggregated and contribute to the performance and mark of the students' group. Thus everyone has a vested interest in how the teammates perform and is aware that this is dependent on their mutual assistance and joint preparation.

The jigsaw classroom. The jigsaw classroom (JC) is considered to be one of the best known models for cooperative learning. The JC was originally suggested by Aronson, Stephan, Sikes, Blaney, and Snapp (1978). It is an approach to promote structured interdependence between members of a group, while still maintaining the need for individual accountability. For a JC the class is divided into small groups of 4-5 students who are asked to learn about a joint topic. The topic itself is divided into sub-units of similar size and responsibility, and each of these is assigned to one of the students. After having become familiar with their piece of information the students from all groups with responsibility for the same sub-unit are grouped together. This is called the expert round. These students now continue learning about their aspect of the topic together with classmates having the same piece to learn. The aim of the expert groups is to develop an explanation and teaching strategy of their sub-topic, to be later shared with the other classmates from the initial groups. The students eventually return to their starting groups and teach and learn from each other about the different pieces of the whole picture (teaching round, see Figure 2).

Subsequent developments of the JC led to different models, including its application to laboratory investigations. The idea of integrating laboratory work with the JC was developed with reference to the method of Group Investigation and was named Peer Tutoring in Small Investigative Group (PTSIG). PTSIG maintains the jigsaw structure as a framework, but includes the Group Investigation method for the work of the expert groups (Lazarowitz & Karsenty, 1990). In addition methods were developed in order to safe-guard the process. These safe-guards are directed at preventing issues with individual team members causing the system to fail. Examples of these safe guards are doubling-up in the expert groups or providing all individuals with optional basic helps of each topic underlying the joint task (Eilks & Leerhoff, 2001; Eilks, 2005).

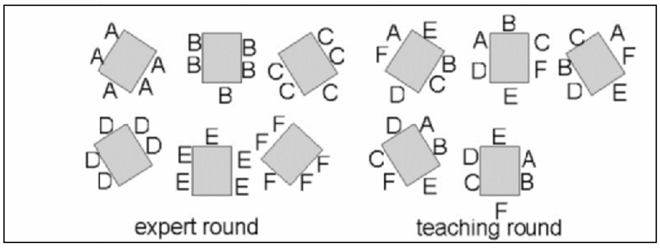


Figure 2. The Jigsaw Classroom

An analytical tool for reflecting on classroom interaction

As an analytical tool for reflecting classroom interaction, but also as a tool to help plan student interactive classrooms, Hertz-Lazarowitz (1992) suggested the six-mirrors of the classroom (SMC) model. This model can serve as a conceptual framework to guide classroom observation in behavioural categories such as "on-task" and "off-task" behaviours, levels of cooperation in the interactions between students, and in aiding the social events that take place during learning. It can be used to design classroom environments and move from traditional whole-classroom instruction to more active and then cooperative learning (Khalil, Lazarowitz, & Hertz-Lazarowitz, 2009).

The SMC model (Figure 3) includes six aspects (mirrors) of the classroom: (1) organisation, (2) learning tasks, (3) instructional behaviours of the teacher, (4) communicative behaviours of the teacher, (5) academic performance of the students, and (6) social behaviours of the student. Each mirror is described in terms of five levels of complexity from simple to complex. The conceptual dynamics between the six mirrors permits the formulation of predictions and the analysis of a range of variables – for example, quality of on-task cooperation as expressed by content, frequency of in-group communication, levels of reasoning, and predicted academic and social outcomes.

The use of the SMC will be briefly explained by comparing two different edges of effectively potential classroom environments. The one edge is considering the traditional teacher-centred classroom where the teacher is displaying information and tries to directly transmit information towards the students, also called frontal or expository instruction. The other edge serving as an example will be a classroom based on cooperative learning.

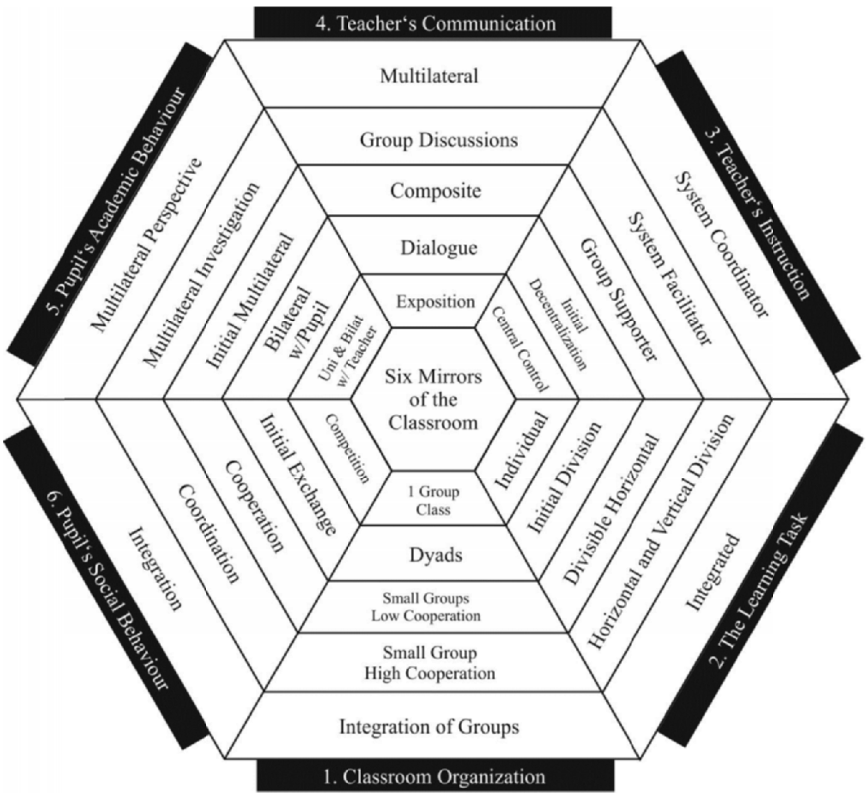


Figure 3. The Six-Mirrors of the Classroom (SMC) model

For the case of frontal instruction, in mirror 1 of the SMC, which examines the physical organisation of the classroom, there is a classroom with the class only forming one group. This is perceived as a fixed classroom with little or no movement of students around the room. The learning tasks (mirror 2) will be presented to the whole class and then, each student tackled the learning task individually. The teacher executes a centrally controlled and strongly guided instruction with the class as a whole (mirror 3), with a high frequency of expositing information by lecturing, demonstrating experiments or using the blackboard (mirror 4). Students' behaviour is limited to individual action or short term interaction with the teacher (mirror 5). Students' social behaviour often is individualistic and competitive (mirror 6). In all the six mirrors such a traditional teacher-centred approach will get low scores for a classroom environment with respect to its potential to support socio-constructivist learning.

In contrast to the frontal instruction, cooperative learning environments will receive higher scores in the SMC. In cooperative learning environments students work in small groups which do interact and are integrated with one another in the fashion suggested in the Jigsaw Classroom (JC) (mirror 1). Learning tasks (mirror 2) are divided horizontally, as in a JC, or vertically and integrated, as in the Group Investigation (GI). These cooperative learning tasks involve peer learning and peer teaching, were designed to increase interdependence and personal as well as collective responsibility and thus form integrated tasks for all learners. The pattern of teacher's communication and instructional behaviours include communication with the whole class for a short period of time, then with each of the groups as well as with individuals who needed help. The teacher becomes the organiser and coordinator of the cooperative classroom (mirror 3). The teachers' communication (mirror 4) becomes multilateral while moving between the groups and helping the students individually or within their groups. The students' communication has a multilateral perspective and their social behaviour is supported by the structured formation of the group and they become socially integrated within the group by feeling their individual accountability together with their positive inter-dependence and the need for cooperation and communication (mirrors 5 and 6).

Thus, using the SMC as a Spider Web (see the example of using Spider Webs to analyse classroom activities in Chapter 1), the area within the spider will give a measure for the classroom learning environments' potential to support socio-constructivist learning. But it also can help to reflect on lesson planning in advance to apply instructional methods.

The variety of methods for making students active – Hands on and minds on

As we saw in the previous section, the dimensions of making the classroom student-centred using appropriate teaching methods offers a wide variety of activities. As the dimensions differ so too do the methods, with the various methods offering a distinct variety of strategies for making the student more active in chemistry teaching, in a hands-on and minds-on fashion. Table 1 provides a selection from the variety of potential methods for the teaching of chemistry. Illustration will be given in the practice part of this chapter. Further examples which work well and have been proved in practice for all of these methods can be found on the Internet or in the literature.

Insights into other methods and their implementation in chemistry teaching can be found in Chapters 1 and 6. The connection of cooperative learning with the use of modern ICT (CSCL, Computer Supported Cooperative Learning) is discussed in

Chapter 8. More methods can be found in the section on hints below for further reading and the Internet.

Table 1. Potential strategies to make students active participants – hands on and minds on

Challenging students' pre-knowledge and ideas, or help to structure and organise them
– Brainstorming and clustering
– Drawings of students' imagination and ideas
– Mind and concept mapping
– Preparing posters, organisers, or digital presentations
– …
Making students' communication the basis for effective learning
– Reciprocal explanations
– Think-pair-share (1-2-4-All)
– The ball-bearing method (Inside-outside-circle)
– Jigsaw Classroom
– …
Using cooperative learning for whole lesson plans
– Peer Tutoring in Small Investigative Groups (PTSIG)
– Students' Teams and Achievement Divisions (STAD)
– Teams Games Tournament (TGT)
– Learning Companies
– …
Allowing students' creativity, play, and everyday life acting in lessons
– Using or inventing card or board games
– Scenic interpretations, drama, or role play
– Making opinion surveys or expert interviews
– Writing newspaper articles or inventing news-spots for TV
– …

THE PRACTICE OF CHEMISTRY TEACHING

Methods for activating and structuring students' thoughts

Based on the theory of constructivism we know that one of the most important factors that affects learning is the students' prior knowledge (see Chapter 4). The construction and reconstruction of meaning by learners requires them to actively form integrated knowledge structures, building on prior knowledge and relevant experiences. Teachers need to apply instructional techniques that help to activate students' existing knowledge structures in order to accommodate new knowledge, but also to allow for exchange in the fashion intended by social constructivism. In the following section, we will present a number of methods to activate, make explicit, and present students' ideas and their existing knowledge structures.

Brainstorming. Brainstorming is a technique used to foster creative thinking for a specific problem or topic (Fisher, 2005). While brainstorming, a group tries to find a solution to a problem or to collect potential ideas on a joint issue by collecting spontaneous contributions associated with the problem or issue, e.g. how to start a practical investigation on a specific topic or which apparatus, set-up, or equipment might be used. Brainstorming can be also used to orient oneself towards a new topic or domain, e.g. to ask the students for their spontaneous associations or prior knowledge of introducing a new topic like salts, acids and bases, or alcohols.

Originally, brainstorming was developed as a group technique. However, it can also be put in practice on a solitary basis. A prerequisite for brainstorming is that it should address one specific question or topic. Sessions that address multiple questions tend to be rather inefficient.

In practice brainstorming can be guided by the following four steps:

– *Strive for a heterogeneous group composition*: Place members with different backgrounds and/or experiences in one group to enhance looking at the problem from multiple perspectives and suspending assumptions. Heterogeneity fosters the generation of a long list of divergent ideas.
– *Start open-ended*: Generate as a long list of ideas as possible for facilitating problem solving. The greater the number of ideas is, the greater the chance for an effective solution will be (quantity breeds quality).
– *Associate and postpone critic*: Association will stimulate the building of ideas. Participants should extend and add to ideas freely. Analysis and criticism should be reserved for a later stage in the process.
– *Combine and integrate*: Eventually, combine and integrate the ideas to form a lower number of categories, and in the end one single (improved) idea might be developed or selected. One way to do this is clustering (see below).

In the last decade numerous variations on the brainstorming technique were developed, aimed at enhancing the creative output, encouraging all participants to have an equal say and reducing social inhibition in the group. In the context of chemical education, brainstorming is mainly used to activate students' thoughts in order to initiate problem-solving activities, or is related to understanding key concepts, such as diffusion (Van Rens, Van der Schee, & Pilot, 2009). Brainstorming sessions are often followed by a class discussion chaired by the teacher. The proposed ideas are shared, reflected upon, classified, and ranked.

Clustering. Clustering is a technique used to classify objects, and thereby offering richer information about relationships by grouping them. Clustering can start from any collection of ideas, words or pictures, but also can be a form of brainstorming.

Rico (2000) suggests clustering as being a technique of brainstorming. One can ask the students to start with a word. They should circle the word and write down each new word or phrase that comes to their mind, circling them too, and connecting them with a line to the word in the centre if it seems like an entirely new direction. But, the students can also make connections between the different circles, so that one big cluster of words and ideas is formed, but also the ideas near to one another form sub-clusters in themselves.

Another technique of clustering is the sorting of words or phrases already set up and documented on pieces of papers or cards (Stanfield, 2002). The clustering starts by sorting related cards together following distinctive criteria, e.g. specific relationships, properties or similarities. Smaller and bigger clusters of cards (and thus of information) are formed and information is organised in a qualitative and quantitative way. Clustering puts students in the position to review their existing knowledge structures and to come up with new patterns, thereby contributing to a flexible use of different representations of their knowledge structures. The outcomes of a clustering can be presented in different ways. The most common way is a one-dimensional depiction of elements obeying a specific criterion. However, the use of two (or higher) dimensional patterns offers the opportunity to classify objects according to two (or more) criteria.

In the chemistry classroom the periodic system of elements offers rich opportunities for performing clustering (Chen, 2010). The teacher can give cards to the students with pictures and names of different chemical elements, e.g. each four of the alkaline metals, the alkaline earth metals, halogens, and inert gases. In addition to the name and a picture of the element, the cards also encompass the GHS-risk pictograms (Figure 4). Students analyse the safety symbols and search for any risk and safety specifications. The cards are then clustered with respect to similar behavior. This may have potential as an initial approach towards learning how the periodic system of the elements is structured.

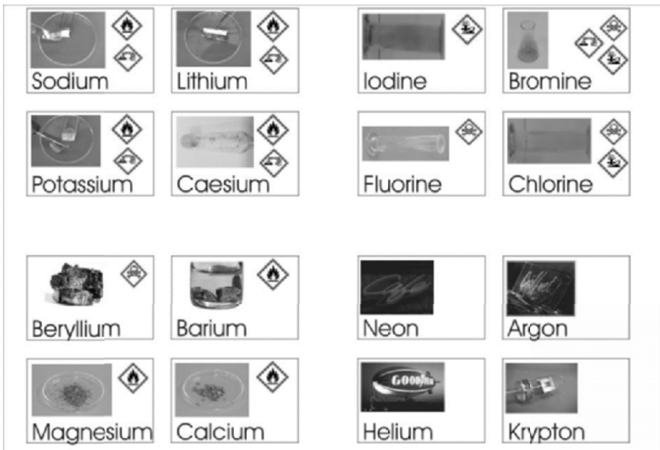


Figure 4. Cards of selected elements for a playful approach towards the periodic system of the elements

Mind and concept mapping. Mind mapping is a technique to represent words, ideas, tasks or other items linked to and arranged around a central key word or idea developed by Buzan in the 1970s. By presenting ideas in a radial, graphical, non-linear manner, mind maps encourage a brainstorming approach to planning and organisational tasks. Mind maps are used to generate, visualise, structure, and classify ideas one has in mind and thus helps to re-organise and reflect already captured information. Mind maps serve as an aid to studying and organising information, solving problems, and making decisions (Buzan, 1996). An example of a mind map on atoms and bonding is given in Figure 5.

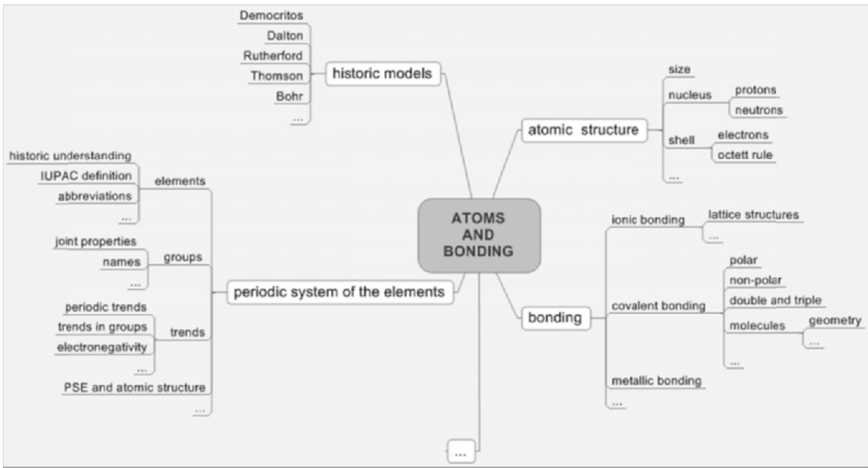


Figure 5. Example of mind map developed by mind mapping software

Related to mind mapping is the technique of concept mapping. A concept map is a diagram showing the relationships between ideas, images, or words. Concept maps differ from mind maps in that concept maps make "*concepts, and propositions composed of concepts, the central elements in the structure of knowledge and construction of meaning*" (Novak & Gowin, 1996). Concept maps consist of nodes (terms or concepts represented as boxes or circles), linking lines (uni- or bi-directional arrows from one node to another), and linking phrases describing the relationship between nodes, such as "gives rise to," "results in," "is required by" or "contributes to." Two nodes connected with a labeled line are called a proposition. Moreover, concept arrangement and linking line orientation determine the map's structure (e.g. hierarchical or non-hierarchical). An example of a concept map on atomic structure is given in Figure 6.

Basically, two different types of concept mapping tasks exist, namely 'fill in the map' and 'construct a map.' In 'fill in the map' students are provided with a concept map in which some of the concepts or linking words are missing. Students are supposed to fill in the blanks (Figure 7). In 'construct a map' students are asked to create their own concept map on a given topic. The question of how much information is provided depends on the teacher. He might give the concepts or linking words or a selection of both.

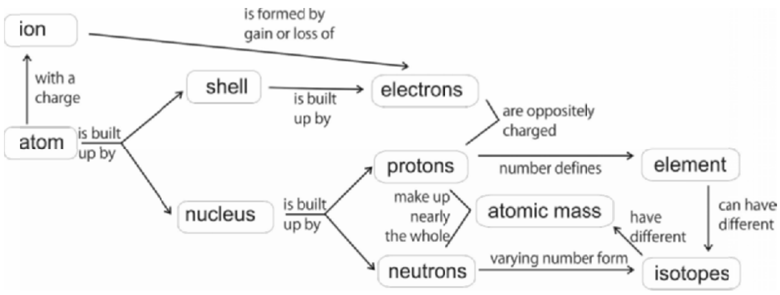


Figure 6. Example of a concept map

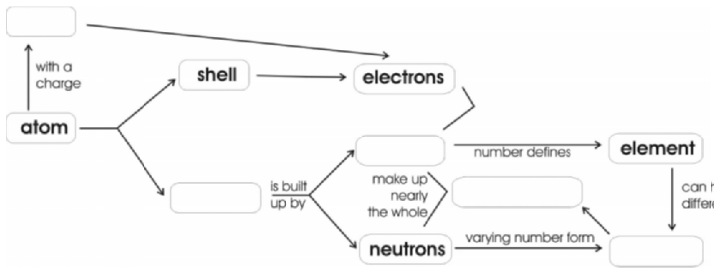


Figure 7. Example of 'fill in' concept map

Before using concept mapping as activity it is needed to familiarise students with the operational definitions of terms applied, such as concept, label, node, linking relationship, proposition, cross-link. In general, the procedure for constructing new concept maps can be described in terms of four (partly overlapping) phases:

– *Brain storming*: Students identify facts, terms and ideas associated with the topic at hand. At this stage, students should not worry about redundancy, relative importance or relationships.
– *Organisation*: All items are classified in groups and subgroups. Students should emphasise hierarchies of the items within groups. Students are free to rearrange items and to introduce new items.
– *Lay-out*: Students make an arrangement that best represents their collective understanding of relationships and connections among groups of items. Students are free to rearrange things at any time during this phase. It should be emphasised that they must pay attention on using a consistent hierarchy in which the most important concepts are placed in the centre or at the top. Related items should be positioned near to each other. The relationships can be made visible using lines or arrows accompanied with a words or small phrases.
– *Finalising*: After the students have agreed on the arrangement that covers their present understanding, the concept map needs to be preserved that others can view and discuss. The creativity of the students is encouraged to use different

colours, fonts, shapes, border thickness, etc. to construct a map. Also ICT-tools might be used.

Finally, the produced concepts maps should be discussed in class. The discussion might be directed by paying attention to the following attributes.

– *Accuracy and thoroughness*: Are the concepts and relationships correct? Are important concepts missing?
– *Organisation*: Was the concept map laid out in such a way that higher order relationships are apparent and easy to follow?
– *Appearance*: Was the assignment done with care showing attention to details such as spelling and penmanship? Is it neat and orderly or is it chaotic and messy?
– *Creativity*: Are there unusual elements that aid communication or stimulate interest without being distracting?

Research has shown that mind and concepts maps are useful tools that reveal students' existing notions and ideas. There are many examples described in which mind and concept maps are used in chemistry education, for instance for the meaningful learning of atoms, bonding, electrons and solutions (Regis, Albertazzi, & Roletto, 1996).

Methods for stimulating communication for more effective chemistry learning

From the theory part in this chapter we know how important communication is for learning (see also Chapter 5). Therefore, in the following section two methods of cooperative learning and associated examples from the chemistry classroom, which place a strong focus on communication, will be discussed.

Think-pair-share (1-2-4-All). This method developed by Lyman in the 1980s looks at joint learning by an iterative comparison of individual solutions (Lyman, 1981). The method focuses on learning as a process of negotiation. It aims to negotiate a common (better) result step by step. Starting from an individual draft, result or piece of work it leads to a common result for a pair of learners and maybe the whole class later on. The method starts by asking students to solve a given task on a sheet of paper. In a second round each a pair of students compares their two drafts and negotiates a joint solution on a new sheet of paper. In the interpretation of *1-2-4-All* (Witteck & Eilks, 2005), each two pairs of students compare their drafts and work out a joint solution. In the end, the whole class selects the best solution or re-organises components of all the solutions into a joint product. In chemistry education, the method can be used in a variety of ways, for example it could potentially be used for the joint development of write-ups of experiments.

A write-up always should be structured by a scheme, making a clear distinction between different parts including: title and date, aims, safety aspects and risk assessment, sketch of the experiment, procedure, observation and results, and finally interpretations and conclusions. Unfortunately, students often (a) do not focus on the most important points of the experiment (from a science perspective) while observing them or writing them up, (b) do not distinguish clearly between procedure, observation, and interpretation/conclusion, and (c) do not see the connection between their experimentation and the theory behind it. This causes problems in the evaluation of the experiments itself but also means that students frequently miss a central point of scientific work. Often it is not clear to the students that carrying out an experiment is essentially proposing a question to nature by the person doing the experiment, whereas the observation is the answer from nature. The interpretation of the finding is a different step while doing practical work. The interpretation can change in the light of new theoretical knowledge, while an observation can never be changed after it has been made. An observation can only be seen differently if the conditions under which the observation has been made have not been clear or unless new experiments are carried out leading to different observations. The pairs-to-share method can help to clarify the role of the different steps in doing an experiment and explain why these steps are divided into different parts in the write-up. Potential steps of writing up the experiment using the think-pair-share are given in Figure 8.

Develop *one* write-up of the experiment!

1. After a demonstration by the teacher, or after carrying out the experiment by the students, all students individually write up the experiment following a given scheme of steps.

2. Pairs of students sitting next to each other agree on a common solution to the given task based on their answers. They write down their solution on a *new* sheet of paper.

3. Each two pairs of students work out a common answer or solution on the given task, based on the pairs' answers. They have to write down their solution on a *new* sheet of paper.
   A scheme following the steps of the write-up is copied on a transparency and cut into pieces containing the single sub-issues.

4. Version a: All groups receive the whole set of pieces from the transparency. They can then copy their solution on the parts of the transparency. The results of each group are presented on the overhead projector. The whole learning group decides about the best solution for each sub-issue. The write-up of the whole group is puzzled together, presented on the overhead projector and copied by the students.
   Version b: Categories 1-4 are filled out by all groups. Categories 5-7 are prepared in divided labor by different groups on the parts of the transparency. The results are presented on the overhead projector, discussed, pieced together and copied by the students.

Figure 8. Writing up an experiment using the 1-2-4-All-Method. To make the work faster steps 2 and 3 can be focused on the description of procedure observation, and interpretation without writing up the other points again. A second way is to give the transparency to the students in advance of step 3. Thus step 3 can be directly done on the pieces of the transparency.

Think-Pair-Share can be used to introduce the writing-up of an experiment, but also can be applied to train the students. Time spent while writing up the experiment in this way will be full of intense discussion and on-task activity. It will lead to several modifications in the write-ups; initial mistakes and weaknesses will be recognised by the students themselves. A better version of the write-up will be generated step by step. But, the method also will help the students to better connect the experiment to their prior knowledge and this may lead to new questions. The method can be also applied to find a joint solution for a theoretical task, e.g. forming a complex reaction equation or mechanism.

The ball-bearing (inside-outside-circle) method. The ball-bearing is a method of cooperative learning developed by Kagan in the 1990s. The method asks the students to explain to each other a newly learned theory in a sequence of different pairs (Kagan, 1994). The ball-bearing employs the idea of reciprocal explanations and each student has to explain the content that they have just heard to an expert, who is there for control, in order to test whether the students' understanding was correct. By forming different pairs of students ball-bearings enable control and assure sufficient support for each learner.

In the interpretation of Witteck, Most, Leerhoff, and Eilks (2004) for the case of chemistry teaching, the whole learning group is divided into two groups of similar size. Both groups work on a specific issue. The issues given to the two groups of students are related to each other, but do not overlap and do not build upon each other. The work can be supported by use of appropriate materials and tasks and should be organised in pairs or small groups. Informative material could be provided, e.g. a few pages from a textbook, different URLs from the Internet, or two experimental tasks. The central task for each group is to understand their issue, and to develop a small presentation of five minutes about their topic. Initially, it is made clear to the students that they will have to explain their part of information as 'experts' individually to one of the students from the other group at a later stage. Questions for self-control can be made available for the students, as well as offering help to explain techniques.

After working on their topics the students form two circles with each two of the learners sitting face to face to one another (Figure 9). One after the other, both experts presents the part of the topic that they have learned. The other person is asked one after the others to listen, to understand, and to make notes during the phase where the partner is presenting his or her topic. This phase should take about 10 minutes. Then the circles are rotated. One circle is rotated clockwise, one counter clockwise by one or two chairs. New pairs of students are generated and are asked to repeat the explanation of the topic presented to them in the first round. The opponent now listens, expands, and corrects. In this second phase all students have also the chance to ask comprehension questions if the explanation in the first round has not been sufficient. In this case, all learners now have new partners who may be better able to explain their topic. Perhaps this is done in another way compared with the initial partner in the previous round. This phase again takes some 10 minutes. After another rotation of the ball bearing both learners in each new pair are asked to look for parallels, differences, and relationships within the two topics.

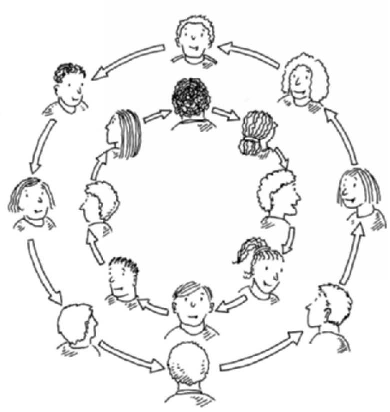


Figure 9. Grouping the students within a ball-bearing

For chemistry education Witteck et al. (2004) suggested different examples. One is, for example the formation, exploration, and refining of crude oil. Different oil companies have websites about their sources of crude oil and their technical processes. One group of students is asked to learn from a selection of Internet URLs about the formation of and prospecting for crude oil, the other group learns about the refining of crude oil and oil-based products. Potential tasks are outlined in Figure 10. After preparing themselves the students are asked to explain to each other the two issues, utilising the ball-bearing method as described above. After the final rotation the students should recognise the relationship of both parts to the whole process of processing of crude oil.

– *Formation and prospecting: Which chemical substances form crude oil? When, how, and from what materials did crude oil evolve? In which regions of the world is crude oil prospected? How much crude oil is prospected per day resp. per year?*
– *Refining: Out of which chemical substances does crude oil consist? What happens in the refinery? What happens in the processes of cracking, hydrogenation, and reforming? What are the most important products coming out of the refinery? How much crude oil is refined per day resp. per year in your country?*

Figure 10. Potential tasks for a Ball-Bearing on crude oil chemistry

The combination of the guided search on the Internet with the ball bearing proved to be an interesting and motivating method. The method helped the students to become clear about what they have to do. Although the evaluation of information is not an easy task and students sometimes feel uncertain about learning information coming exclusively from their classmates, these considerations diminish after applying respective techniques several times. In the end, the students enjoyed working in this way and their achievement improved.

Methods for learning chemistry in a cooperative mode

The literature (e.g. Sharan, 2004) suggests a lot of different techniques to promote cooperative learning. Think-Pair-Share and the Ball-Bearing method presented above are two of the methods. In the following section two examples for organizing a whole lesson plan in a cooperative mode will be presented and illustrated by examples from chemistry teaching.

Introducing atomic structure in a jigsaw classroom. In the jigsaw classroom (JC) by Aronson et al. (1978) a topic of interest is divided into several pieces of similar size and complexity. The students are grouped into groups of equal size. The number of students in each group should not differ much from the number of the groups. So for a class of 30 students a group size of 5 or 6 students is a good option. Each student gets one part of the materials. The students start to individually work through the material, to try to understand and in some cases to solve respective problems. Following that, all those students working on the same task form an expert group. In the expert groups they continue working on the content and to clarify any lack in understanding. They jointly prepare a teaching strategy to later on explain the information to the other students. Following on from this work, the groups are rearranged in such a way that new groups are formed with each new group consisting of one student from each of the expert groups. In this fashion the students teach each other, following the strategy they planned in the expert groups' work (see above and Figure 2).

The teacher should be aware that this is an ideal description. A lot of communicative as well as social abilities are necessary to lead to successful performance. The objective, to let the students plan the teaching strategy for the second part of the work, is rather cognitively demanding. Younger students are often not able to do this, particularly if they are not trained properly. This causes dangers for learning especially in cases where new and essential tasks have to be worked out. It is recommended that help in the form of guidance and specific tasks should be provided by the teacher to ensure the smooth dynamics of the method. Another method to alleviate issues is to double the expert groups (Eilks & Leerhoff, 2001). A doubling of the expert groups makes the system more secure because it gives each teaching group two experts who prepared themselves independently (Figure 11).

An example for the latter case is introducing atomic structure by a JC (Eilks & Leerhoff, 2001). The JC itself contains three different areas each carried out by two expert groups. In the expert groups the students work out (a) Rutherford's experiment and the nucleus-shell-structure, (b) the structure of the atomic nucleus,

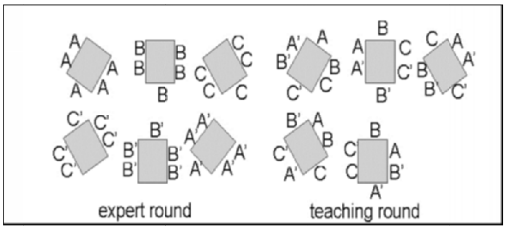


Figure 11. Rearrangement of the groups from doubled expert to teaching groups

and (c) structure of the atomic shell. Potential tasks are given in Figure 12. Different texts, questions and small experiments aid the students in solving their task.

Group A/A'
Rutherfords experiment and the nucleus-shell-structure of the atom
Radio activity
Charges and their behaviour
Rutherfords experiment in a shoe box
Rutherfords experiment
The relation between nucleus and atom
Diff.: The life of E. Rutherford

Group B/B'
Structure of the atomic nucleus
Electrostatic distraction
Model on distraction with magnets
Sructure of the atomic nucleus
Atomic masses, isotopes
Diff.: Radio carbon method

Group C/C'
Structure of the atomic shell
Electrostatics and frictional electricity
Structure of the atomic shell
Shell occupation and octet rule
Electron configuration of different atoms
Ionisation energy and investigating the shell
Diff.: Rare gases as inert gases in bulbs

Figure 12. Tasks for the expert groups in a jigsaw classroom on atomic structure

After working out the experts' tasks the groups are rearranged as described above. The teaching round includes a report about the work done in the expert groups as well as an exchange and shared clarification of the main terms and rules, with the objective that every students must be able to provide all of them afterwards. Additionally the students have to solve different tasks on the structure of atoms of different elements together. This means adding all possible information about several element atoms from the given information (number of protons, neutrons, electrons, atomic mass, and structure of the atomic shell). At the end the students are asked to compare the atoms from different groups from within the periodic system of the elements and to search for parallels and trends.

Introducing the structure of atoms by the JC has the potential to make the teaching of this theoretical and demanding phase student-active. From the classrooms we know that the students develop a positive attitude towards their learning of chemistry and the gained concepts while learning about them in the JC. Research revealed that this way of introducing atomic structure worked well and helped to reduce deficits in learning, while also keeping students motivated throughout this difficult phase of chemistry education (Eilks, 2005).

A learning company on acid-base-chemistry. The learning company method (LC) by Witteck and Eilks (2006) is a didactically-constructed classroom structure, analogous to existing or "ideal" companies. Originally, the LC idea was thought to simulate practical, profession-oriented tasks in vocational education. Through a model based on already-existing or idealised companies, students were supposed to learn how processes in a company occur. This is not the in the core of chemistry teaching. However, there are possibilities of using learning companies for the motivation and the encouragement of student-active and cooperative learning also in the chemistry classroom.

Witteck and Eilks (2006) adopted the idea of the LC for chemistry education. Within a chemistry LC it is intended that all necessary steps of learning chemistry should be performed by the pupils on their own, based in small learning groups, starting from open-ended tasks and based on experimental work. Open experimental tasks are assigned to the students instead of prescribed "cookbook recipes" being provided to the students (see Chapter 6). These open tasks are framed within a fictional story of a company with different departments. The assigned experimental problems must be conquered through self-organised and self-responsible learning within groups of students (the departments). The problems are presented so that no experimental direction is to be given. Instead, goal-oriented work orders and a folder of materials are provided so that the exercise can be solved without resorting to a prescribed path.

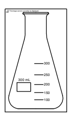
The LC should be illustrated by an example from the chemistry of acids and bases: The *Max Sour Ltd. Learning Company* (Witteck & Eilks, 2006). The objective of the Max Sour LC is to include all relevant aspects of acid-base chemistry into the LC lesson plan, theoretically as well as in the hands-on aspects. Initially, students are divided into small groups (departments of the Max Sour Company). Each group is composed of 4-5 students as a mix of different achieving learners. A folder is provided for their particular department. Max Sour Ltd. has up to seven different departments. E.g. the research department "Synthetic Indicators" is ordered to produce an optimal universal indicator by mixing several different indicator solutions. A large number of indicators are provided for the task. The pupils must discover a good combination of the solutions so that they can differentiate between a pre-set range of pH-values (1, 4, 7, 10, 14). A second example is the research division "Plant-based Indicators." They are ordered to produce a new, natural indicator from radish peels. An indicator handbook must be written, including a colour scale which makes predetermined pH-change points visible. But there are also analytical departments, or a group for the canteen (being ordered to find out why red cabbage sometimes turns blue and how to make a business out of it), or a group of janitors (being asked to find a way for the company's canteen to clean calcified heating-elements in the dishwasher and to free a plugged drainpipe using acid-base-chemistry).

In all departments, the pupils receive instructions from a fictitious "executive department" member allegedly in charge of the various departments (the teacher). All orders include a small story related to a possible problem which might occur in a company. The stories instigate the investigation of and the products surrounding acids and basis. The student groups receive their work orders, including equipment and chemicals. Each work order is to be solved through experimentation. Only the stated problem and the materials which are available for the various departments are listed on the work order. They do not contain instructions for experimental procedures or apparatus construction. Pupils are supposed to plan and execute the experiments using their own initiative. Figure 13 gives an overview of the lesson plan.

The Max Sour Learning Company

The Max Sour Company has seven departments. You will form these departments. You will receive work orders from the "boss," which you must complete.

Form groups (departments) of 4-5 students. You will work in these groups for the next few periods and display your findings at the end in a fair. Each pupil will receive an identification tag showing his or her department and name.



You have approximately 1-2 hours for the planning and preparation of your experimental doing and another 4-5 periods for conducting them, to learn about acids and bases, and to create a poster. All experiments must be discussed with your teacher before you carry them out. Every activity must be carefully documented. Every experiment must be written up using correct scientific terminology.

Aside from working on your experimental tasks, answer the questions for your specific area in the general question catalogue with the help of the computer learning environment, your textbook, or the Internet.

Create a poster which summarises all of the work and experimental results from your particular department.

Note: The work of the entire department is the most important factor!

Figure 13. The Max Sour learning company

Due to the open-formatted, independent nature of the students' experimentation, they must carefully plan and discuss exactly how they want to perform their experiments. But, the students are also guided through learning by different sets of questions for the theory and everyday life applications. The textbook can be used, as can a specific learning environment on the internet (The Max Sour Ltd. Intranet), which provides help where needed. Finally, the students have to present their department, their experimental solutions and the theory that they used at a fair showing up the potential of their department and of Max Sour Ltd. as a whole.

The learning company approach clearly proved that it encouraged students to work actively, flexibly, and with more self-direction on their experimental tasks. The pupils planned, worked and thought independently and carefully organised their work. Self-organisation was provoked by use of the open-ended work orders, which could only be solved through discussion, inquiry, and the exchange of information within the groups. Another example is described in Witteck, Most, Kienast, and Eilks (2007).

Scenic interpretations, drama, role-play, and the mimicking authentic practices in chemistry education

In the last section of this chapter we shall present quite unconventional methods for the learning of chemistry. Examples will be outlined illustrating how these methods can be used to activate the students learning of essential chemistry. In the first two examples we will discuss how physical interpretations can help students to better understand the particulate nature of matter, and how drama can be used to learn about the nature of science. The other two examples will discuss the idea of role-playing and mimicking authentic social practices to understand about how chemistry is handled in and by the society.

Using drama to understand ptarticle concepts. Understanding the different representations of chemistry is one of the most difficult parts in chemistry education, for example, understanding chemical phenomena on the particulate level is challenging for students (see Chapter 4). Using a drama interpretation of the particulate level can help students through making physical experiences about the particulate level. This experience has the potential to promote understanding and can serve as an anchor for transferring knowledge in the long-term memory.

An example concerning the states of matter may illustrate this. The states of matter (solid, liquid, and gaseous) are differentiated by the motion of the particles which they are composed of and the distance between them. In the solid state particles have fixed places in a lattice structure. They are near to each other and move only slightly. In the liquid state particles are still near to each other, but can move freely. In the gaseous state there is free movement and a lot of empty space between the particles.

To promote understanding, one idea is to take the group of students and to ask them to stand close to each other. With 'growing temperature' the students are asked to increase their movement step by step. They will find out that it becomes difficult to keep their fixed places. By another raise in motion the students will see that the distance between them will increase, and in the end by nudging each other students will leave the 'particle formation.' The matter will start to 'evaporate' (Figure 14). The experience of this motion will serve as an aid for understanding the states of matter and their changes and will act as an anchor for the students' memory.

Figure 14. Students interpreting the states of matter the solid state (left), via liquid (middle), to the gaseous state (right) (Eilks & Bolte, 2008)

For more ideas see Sciencelearn (2012). A related example on introducing different types of chemical bonding was recently described by Ozden (2007).

Using theatre play to learn about the nature of science. For more personalised topics a theatre or role play can be used. Atomic structure is a good example. Throughout the history of chemistry different models for atoms and atomic structure were available. For true understanding of the nature of science (see Chapter 1), it is important that the students learn about the tentativeness of these models. The students should learn that the creation of models is usually bound to individual chemists and that models can replace each other in the light of new evidence. Forming a theatre play between big chemists from history (Democritus, Dalton, Rutherford, Thomson, & Bohr) can help students to understand, that all these ideas were brilliant at that particular point in time, but also that all these models are tentative in nature and were replaced at some point in the light of new findings (Craft, 2007).

Using theatre plays to learn about the different models and the history of chemistry can be carried out in a variety of different ways. If time and the students' skills allow for it, the students can write their own storybook of a fictitious meeting of the different representatives of atomic models. A dialogue between the chemists can be written, with the one for each individual explaining and justifying his model leading to a reflection on the different proposals, their power with respect to their time but also their limitations in the foreground of our current understanding. Students can create costumes to make clear, whose role they are playing. Students with good knowledge in the content and skills involved in argumentation might be allowed to add a phase where they start debating without the pre-scribed storybook. For those students who are not able to write the storybook themselves, the teacher can prepare it and ask the students to play and interpret it.

While acting out the drama better understanding will develop. The role play and the preparation for it can offer students good motivation for comparing the different models (in their potentials and limitations), but also will enable learning processes about the tentative nature of models and their connection to the time their 'inventors' lived in.

Role-play about the handling of chemistry issues in society. Learning chemistry is more than only memorizing chemical facts and theory. Chemistry education also encompasses an understanding of the interplay of chemistry, technology, and society (see also Chapter 1). A role-play or business game can help offer an insight into the different roles individuals within society have when decisions about chemistry and chemical technologies are made.

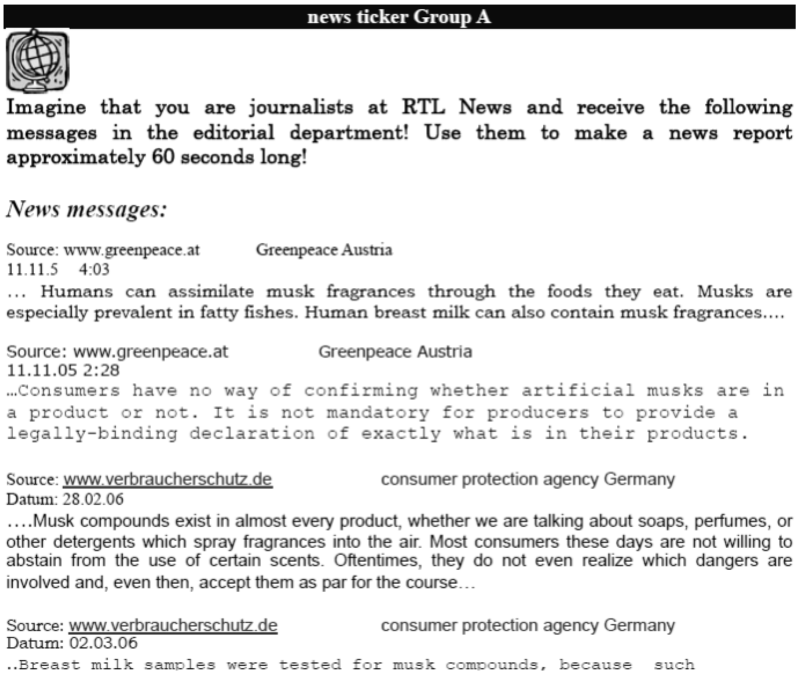
The role of renewable energy sources can serve as a good example. In the case of bioethanol we face a controversial situation. Renewable energies are of value to reduce the emission of greenhouse gases and to protect crude oil resources for the future. However, the decision is made within a framework of scientific, economical, ecological, and social questions and issues. After learning about the science background, role play can help students to better understand that the decision about the use of bioethanol is not only a scientific one. Based on role-cards, texts and internet pages groups of students prepare themselves for a discussion about the use of bioethanol. Role-experts might come from the car manufacturers, environmental and climate protection groups, the agricultural industry, development assistance groups, or the consumers. After having prepared each one of them, the students in a role play can mimic a TV talk show or a parliaments hearing to whether the use of bioethanol in cars should be promoted by the politics. An example is described in Feierabend and Eilks (2011).

Also in the context of industrial-chemistry oriented teaching (see Chapter 1) role plays and society-oriented discussions can be used (Reid, 2000). Several projects in different countries introduced such topics into the regular secondary chemistry teaching. The respective lessons were usually interdisciplinary in nature to integrate learning of chemistry concepts with its related societal and technological applications, e.g. the industrial chemistry units developed in Israel by Hofstein and Kesner (2006). Also in these projects, the students are involved in debates about the location of an industrial plant. They have to consider many criteria such as natural resources (availability of raw materials), geology, environment, labour, economical and all kind of technological applications

While discussing in the role plays the students will learn about the different arguments which are held by the different interest groups in society. But, they will also learn that decisions on the use of a new technology nearly always have to be made in a field of contradictory opinions and effects (see Chapter 1).

Mimicking authentic societal practices in chemistry education. To learn about how scientific information is handled in society the mimicking of societal practices proved to be educationally effective. Role-plays and business games (see above) or playing out the evaluation process in a consumer test (see Chapter 1) are options. But also dealing with media reports or advertisements can lead to a reflection on the multidimensional character of evaluations processes about chemistry within society.

For this purpose, Marks, Otten, and Eilks (2010) suggested the idea of working as a journalist. Among the different examples that this method illustrated it was indicated that it always is the individual that changes information while transmitting it (Eilks et al., 2012). One of their examples deals with the problematic nature of musk fragrances in cosmetics. Having learned about the chemistry behind this topic the students form different groups. Every group gets a 'newsticker' (Figure 15). A newsticker is one page of quotes taken from the internet. The newstickers were made by utilising a Google search. For each newsticker a different search was made. The search is always combining two terms, one of them in all the four cases within this example was 'musk fragrances,' but the second terms differed. In the end the separate newstickers reflect the following perspectives: (a) consumer protection (concerns about potentially hormone-activating or carcinogenic substances), (b) innovative products (cost and sales pressure to market a competitive product), (c) wastewater treatment (problems and costs for local authorities), and (d) environmental protection (effects of synthetic musks on the environment).


news ticker Group A

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

News messages:

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

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

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

Source: www.verbraucherschutz.de consumer protection agency Germany
Datum: 02.03.06
..Breast milk samples were tested for musk compounds, because such

Figure 15. Start of a news ticker for the journalist method

The class is divided into eight groups consisting of 2-4 students per group. Each two separate groups of students receive identical newstickers, so that each of the four perspectives is repeated in a double format. The students are asked to write a 45 second report for the evening news on TV. The students are given about 30-45 minutes time to complete this task. The doubling of the groups for each of the newstickers is done so that it becomes clearly visible that totally divergent presentations can arise from using exactly the same information sources.

In the final phase, the pupils present their news spots. The role of the journalist/editor becomes explicitly clear in this exercise. The pupils generally recognise the problematic nature of the exercise early on and quickly connect, not merely to the ulterior motives behind the various interest groups, but also to the exaggerations and omissions frequently used in media reports. The learners show evidence of wide-ranging cognitive levels of reasoning ability, especially when the conversation is steered in a direction suggesting solutions to the problem.

SUMMARY: KEY SENTENCES

– Social constructivism suggests that learning is a process mainly built on student-activity (hands-on and minds-on) and communication.
– Student-centred teaching methods are essential to provoke effective thinking among students and to provide structured frameworks for communication and cooperation, which will ultimately help to enhance effective learning in the chemistry classroom.
– Teaching methods provoking the explication of thoughts, promoting communication and supporting mutual assistance between the learners proved to be more successful for the learning of chemistry than the pure dissemination of facts and theories which takes place in frontal teaching.
– In the core of student-centred methods is cooperative learning. Cooperative learning means the structured interdependence and collaboration of the learners towards each other. Quality criteria for cooperative learning are individual accountability, positive interdependence, face-to-face promotion of interaction, group processing, and interpersonal and small group skills.
– Varying the teaching methods allows for enabling the students to become active learners. Brainstorming, mind and concept mapping, or clustering help for organising and exchanging thoughts. Methods like Ball-Bearing, Think-Pair-Share, the Jigsaw Classroom or the Learning Company proved to provoke class cooperation, promote motivation, and raise achievement in chemistry learning. Scenic interpretations, drama, or role-play can help to enrich the chemistry classroom, motivating students and achieving a broader range of goals.

ASK YOURSELF

1. Explain: What is the ‘social’ dimension within social constructivism?

2. Repeat the quality criteria for cooperative learning as outlined by Johnson and Johnson (1999).
3. Think about a mind map and a concept-map on the topic of acid-base-chemistry. List advantages and disadvantages for both forms of visual representation.
4. Outline a sketch of how you would organise a lesson on the topic of alcohols utilising the ball-bearing method.
5. Draw a sketch outlining a jigsaw classroom for the teaching of carbohydrates in a secondary chemistry classroom.
6. Remember the scenic interpretation for the states of matter and their change. Outline a scenic interpretation for the process of dissolution of sugar in water.

HINTS FOR FURTHER READING

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Lazarowitz, R., & Hertz-Lazarowitz, R (1998). Co-operative learning in the science curriculum. In B. J. Fraser & K. G. Tobin (eds.), *International handbook of science education* (pp. 449-470). Dordrecht: Kluwer. This handbook chapter gives an overview about the evidence science education research gained in the field of cooperative learning.

Sharan, S. (ed.) (2004). *Handbook of cooperative learning methods*. Westport: Praeger. This handbook gives an overview about a large variety of methods how to apply cooperative learning in the classroom.

Ginnis, P. (2002). *The teacher's toolkit: Raise classroom achievement with strategies for every learner*. Camarthen: Crown Publishing. The book offers a plenty of different methods how to organise the classroom by a variety of different methods.

Naylor, S., Keogh, S., & Goldworthy, A. (2004). *Active assessment: Thinking, learning and assessment in science.* Sandbach: Millgate House. The book focuses tools and examples for student-active learning and assessment in the science classroom.

Herr, N. (2007). *The sourcebook for science teachers*. San Francisco: Jossey Bass. The book offers a variety of methods and examples to enrich science teaching. See also the online offers accompanying the book at sciencesourcebook.com.

RESOURCES FROM THE INTERNET

Jigsaw Classroom: *www.jigsaw.org*. The official site explaining everything around the jigsaw classroom technique.

Kagan Online: *www.kaganonline.com*. The site of S. Kagan offers tips and access to a lot of materials for student-active learning and professional development of teachers.

Methodpedia: *de.methopedia.eu*. Methopedia is a collection of teaching and assessment methods that can be used in chemistry classrooms on all levels.

Sciencelearn: *www.sciencelearn.org.nz*. This website from New Zealand offers a big variety for alternative teaching ideas in all fields of the sciences.

NSTA: *www.nsta.org*. The site of the National Science Teachers Association from the USA offers a lot of materials and publications for enriching the pedagogies in all fields of science teaching

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YEHUDIT JUDY DORI, SUSAN RODRIGUES & SASCHA SCHANZE

8. HOW TO PROMOTE CHEMISTRY LEARNING THROUGH THE USE OF ICT

This chapter presents a view of using and incorporating information and communication technologies (ICT) into the teaching and learning of chemistry. Studies that investigate students' ICT skills in chemistry in particular and in science in general establish that ICT-based learning environments play a significant role in education. While this seems to be true as an overall assessment, the future is affected by innovations, fast-moving, and in many ways unpredictable. This chapter discusses and exemplifies visualisations in laboratories such as molecular modelling, data collection, and presentation. We focus also on ICT use via the World Wide Web (WWW) and virtual reality as well as the role of ICT for developing higher-order thinking skills, such as inquiry, graphing, and modelling. In addition examples of different assignments for teaching chemistry using ICT are introduced including some recommendations for the designing of new ones.

THEORETICAL BASIS

> *Good teaching remains good teaching with or without the technology; the technology might enhance the pedagogy only if the teachers and students engaged with it and understood its potential in such a way that the technology is not seen as an end in itself, but as another pedagogical means to achieve learning and teaching goals.*
> (Higgins, Beauchamp, & Miller, 2007, p. 217)

Information and communication technology for learning

Information and communication technology (ICT) is a general term that emphasises the integration of telecommunications, computers, software, and audio-visual systems to enable users to create, access, store, transmit, and manipulate information (Stevenson, 1997).

During the last five decades, five generations of learning technologies for science education can be recognized:

– At the beginning of the 20th century, the use of physical instruments, such as magnifying glasses, thermometers, models, and microscopes became common (Gabel, Briner, & Haines, 1992).

I. Eilks and A. Hofstein (eds.), Teaching Chemistry – A Studybook, 213–240.

- The introduction of electronic devices such as television, videotapes, and text-to-speech systems was made in the 1960s (Dhingra, 2003).
- In the mid 1980s, computers spread all over the world while enabling rapid data collection and analysis (Nakhleh & Krajcik, 1994). A few years later, chemists started using animations, virtual molecular modelling, and visualisations (Dori & Barnea, 1997; Kozma & Russell, 2005).
- In the 1990s the Internet and the World Wide Web (Tuvi & Nachmias, 2003), were launched and rapidly emerged to become important resources of information and communication in general, and in science education in particular (Frailich, Kesner, & Hofstein, 2009).
- Nowadays, a variety of learning technologies are being used by educators to enhance learning and teaching, such as learning management systems (LMS), high-level 3D animations, mobile devices, virtual reality, and distance learning software. Science educators and researchers have encouraged the use of ICT in the science classroom of both high school and tertiary education (Chiu & Linn, 2011; Dori, Barak, & Adir, 2003; Ng, 2010; Rodrigues, 2010).

Use of ICT in science education

The terms 'Web' and 'Internet' in this chapter, as well as in the literature, are used interchangeably. Each of the terms, serves several purposes such as integration of virtual simulations, models, and dynamic visualisations, for creation of learning communities, and designing learning environments (Chiu & Linn, 2012). Pre-service and in-service chemistry teacher education should build up competencies to quickly catch up with new developments and to integrate them into classroom practice. Osborne and Hennessy (2003) identified several ways for teachers to make effective use of ICT, among them:

- Ensuring that ICT use is appropriate and 'adds value' to learning activities,
- Building on teachers' existing practice and on students' prior knowledge,
- Structuring activity while offering students responsibility, choice and opportunities for active learning,
- Prompting students to think about new concepts and relationships, to participate in discussions, to analyse critically data and information, and to focus on research tasks,
- Linking ICT use to ongoing teaching and learning activities, and
- Encouraging students to share their ideas and findings.

In chemistry and physics education, the most common ICT tools are visualisations such as simulations or computerised molecular modelling (CMM) and computerised laboratories also known as microcomputers based laboratories (MBL).

It is interesting to compare the level of ICT and visualisation usage in physics teaching to that of chemistry teaching. In spite of extensive development of visualisations in the field of chemistry (Chiu & Linn, 2012), especially in the context of computerised molecular modelling, the MBL elements of visualisations in chemistry have not been thoroughly investigated (Dori & Sasson, 2008). The situation in physics is almost the opposite. Although MBL has been extensively developed, applied, and researched (Thornton & Sokoloff, 1990), the other aspect of visualisations, namely passive and active animations or simulations, are much less established. Most of the studies reported inconclusive results when they described the effects of simulations in mechanics on learning (Redish, Saul, & Steinberg, 1997). Even fewer reports on simulations exist in the field of physics in general and electricity in particular (Beichner, Dori, & Belcher, 2006), and investigation of their learning gains is rare. Research outcomes of the Technology-enabled Active Learning (TEAL) project for teaching physics at MIT (Dori, Hult, Breslow, & Belcher, 2007) indicated that the learning gains were significantly greater than those obtained by traditional lectures and recitation settings without the use of ICT. The research results will be thoroughly explained further in this chapter.

In the following section basic theories are reviewed in order to explain how ICT can serve to improve meaningful learning.

Learning with visualisations: The dual-coding theory

One of the most often used theories for understanding learning with ICT is the *dual-coding-theory* developed by Paivio (1986) and elaborated by Mayer (2003). According to the dual-coding theory, when words and pictures are presented near each other, students can hold the words and the pictures in their working memory at the same time. This effect enables them to integrate visual and verbal models and participate in active learning more efficiently.

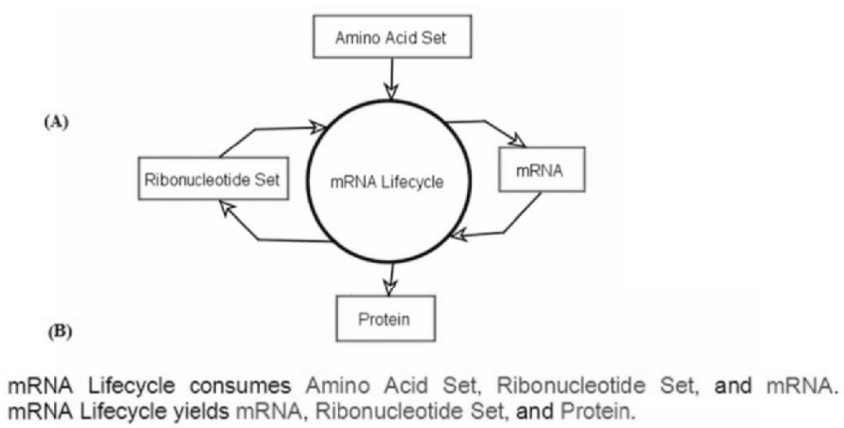


Figure 1. An OPM model that exemplifies dual channel processing

Exemplifying dual channel processing, Figure 1 (Dori & Choder, 2007) is an OPM (object-process methodology) model (Dori, 2002) of the mRNA Lifecycle process – the ellipse in the centre. The diagram shows an amino acid set, which is the object this process consumes, protein, which the process creates, and two recycled objects. This graphic description is automatically translated into the sentences below the diagram, enabling the human viewer to inspect both the text and the graphics for enhanced understanding of the model.

The dual channel assumption is that humans possess separate information processing systems for visual and verbal representations. For example, information in graphs that are constructed on the computer screen immediately during lab-experiments, are processed by students using their visual/pictorial channel. When the students, who carry out the experiments, speak to each other and discuss the results, their words are processed in the auditory/verbal channel. The limited capacity assumption is that the amount of processing that can take place within each information channel is limited and therefore, the combination of both visual and textual information is crucial. The active learning assumption is that meaningful learning occurs when students engage in cognitive processes that include words and pictures. The learning occurs when students organize and integrate these words and pictures sometimes while sharing their understanding with peers, while the prior knowledge serves as an organizer for creating coherent verbal and pictorial representations.

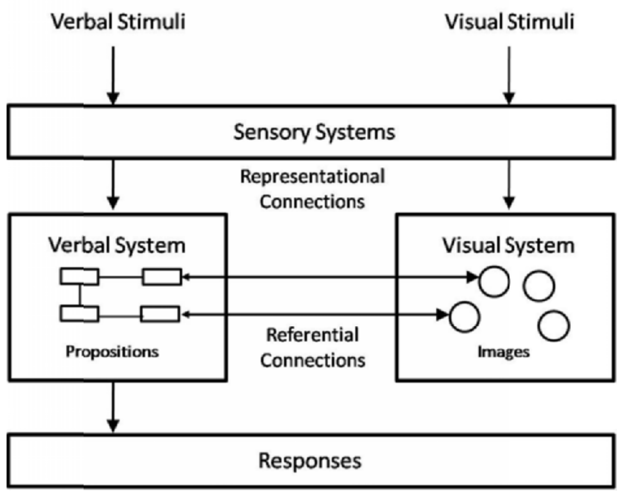


Figure 2. The dual coding process

Researchers emphasise that illustrations should be chosen with thoughtfulness to how they contribute to students' understanding (Barak & Dori, 2011). While low achievers might suffer from the presence of redundant illustrations, researchers found that when illustrations are carefully designed and integrated in high quality to the learning materials, students with low prior knowledge benefit from them the most (Mayer & Gallini, 1990).

Studies on the use of ICT in chemistry education

Analysis of the literature on the use of ICT in chemistry education shows that there is a significant body of work reporting on the potential of ICT in learning chemistry and the benefits to the students' in terms of:

- Animations and dynamic visualisations (Barak & Dori, 2011; Chiu & Lin, 2012),
- Audience response systems (Rodrigues, Taylor, Cameron, Syme-Smith, & Fortuna, 2010),
- CD-ROMs and simulations (Eilks, Witteck, & Pietzner, 2010),
- Data loggers and sensors (Dori & Sasson, 2008; Nakleh & Kraijczik, 1994),
- Emails (Van der Meij & Boersma, 2002),
- Internet (MacKenzie, 2010),
- Computerized molecular modelling (Barnea & Dori, 1999; Dori & Kaberman, 2012),
- Virtual worlds (Zacharia, 2007), and
- Whiteboards (Murcia, 2010).

For several decades, much of the aforementioned research provides both rhetoric and discussion involving ICT in chemistry education. It has alluded to aspects of control, proactive learning, and increased student motivation and engagements. The literature also suggests that there is a growing body of research linking computer games culture, student interest, and the development and design of appropriate ICT for chemistry (Eilks et al., 2010).

Together with these issues, there is also a body of research on observed gender differences when ICT is used in teaching and learning. However, as most of that literature does not pertain specifically to learning and teaching of chemistry, we comment only briefly about these findings. Taylor, Nelson, and Sofres (2002) suggested that boys had a wider range of uses for the technology in comparison with girls. In contrast, Schott and Selwyn (2000) suggested there were no significant gender differences, probably because the technologies have become more common in society and learning environments. We assume that the disagreement may be due to socio-cultural factors.

Motivation and interaction: Arguments for the use of ICT in chemistry education

Research on using ICT in chemistry is often influenced by the potential of the ICT to motivate students. This motivational impact of technology on students' learning is extensively documented in the literature (Rodrigues, 2010). The basic argument is that students are motivated to learn with ICT because it affords ownership and control with respect to pace and choice of content. In addition to the research on motivation, there is also a body of research influenced by a suggestion that the combination of goal-orientation, interactivity, and feedback produces enhanced learning outcomes (Rodrigues, 2010). Several studies have validated the usefulness of virtual e-learning environments in supporting science education (Limniou, Roberts, & Papadopoulos, 2008). However, currently, there are also caveats, such as those raised by Chittaro and Ranon (2007), who have suggested that it might be difficult to acquire funding for students to participate in virtual worlds, and that changes in teaching style and/or even changes at the fundamental level in terms of the formal learning environment, be it the classroom or tertiary laboratory, might be in order.

Sometimes the argument for interactivity accompanies the case for student empowerment. Avatars (a graphical representation of the users or their alter ego) can be created by the user, and hence incorporated in effective classrooms as a character when they submit information on whiteboards. They also allow for simulation design, hence looking at interaction, simulations, avatars, and whiteboards all afford the user some measure of personalised learning. There is a body of research exploring student empowerment through development of computer games for students (Lim, 2008). There is also research documenting virtual character research (Rebolledo-Mendez, Burden, & de Freitas, 2008), which describes pedagogical agents in the form of online virtual characters. For example, Rebolledo-Mendez et al. (2008) talked about designing serious games and avatars for higher education, where cognitive and motivational modelling is integrated into a virtual learning situation. However, this research barely explored the use of such avatars in teaching and learning chemistry.

Science is a body of knowledge agreed to by an informed, critical, and analytical group of people. In terms of communication, scientists often fail to communicate the fact that science is a social endeavour. To improve this state of affairs, Tytler, Peterson, and Prain (2006) suggested that learning environments must allow for "*constructing and refining representations*" because this was "*a core knowledge construction activity within science*" (p. 17). In chemistry teaching, we need to encourage students to understand the assumption and practices in order to make informed sense of the data students collect and analyze. Yore and Treagust (2008) suggested that there is a need to place a greater emphasis on the role of the teacher as someone who models scientific practice and values. The teacher needs to show how scientists make sense of new knowledge and to ultimately communicate effectively and meaningfully in society.

Research reporting on visualisations in laboratories: Molecular modelling, and data representation involving ICT

Laboratories provide students and teachers with unique opportunities for science teaching and learning (see Chapter 6), as well as enhancing students' interest, motivation, and learning scientific concepts. School laboratories can serve as a platform for collecting and interpreting on-line data (Nakleh & Krajcik, 1994), and for fostering visualisations, conceptual understanding, and transfer between molecular representations (Dori & Kaberman, 2012). Use of a MBL enables students to connect multiple representations of scientific processes and phenomena (Stratford, Krajcik, & Soloway, 1998). In science, MBLs have been widely researched over the last thirty years (Tinker, 2009). The general consensus is that MBL helps students with both data collection and visualisation, enabling them to interpret graphs (Russell, Lucas, & McRobbie, 2004). Since most of the technical work in IT environments is done by a computer in real-time, students can be free to solve problems, generate knowledge, and employ higher-order thinking skills.

Hofstein and Lunetta (2004) reviewed developments in integration of computers into laboratory experiences. Inadequate professional development and growth for teachers is the main challenge for effective use of technology in the classrooms. Science educators have been requesting adequate support and development programs for preparing both pre-service and in-service teachers to face these challenges (Dori, Barak, Herscovitz, & Carmi, 2005).

Utilization of computers in science classrooms for collection and analysis of data may help strengthen students' graphing and problem solving skills (Krajcik, Mamlok, & Hug, 2001). These activities enable real-time representation of both abstract (graph) and concrete (experiment) processes (Adams & Shrum, 1990). The use of sensors and data loggers in laboratories may release students from data collection and processing and help them to focus on problem solving and the generation of knowledge while employing higher-order thinking skills (Rodrigues, 2010). Integration of real-time graphing technology into science can help develop deeper understanding of science concepts by linking phenomena with graphic representations (Dori & Sasson, 2008).

Visualisations foster conceptual understanding and transfer among multiple molecular representations (see Figure 3; Kaberman & Dori, 2009). Wu and Shah (2004) identified three difficulties in comprehending and interpreting representations: representing chemical concepts at the macroscopic level rather than the submicroscopic or symbolic level (see Chapter 4), comprehending visual representations by surface features, and interpreting chemical reactions as a static process. To help students understand chemistry concepts and develop representational skills through supporting thinking, Wu and Shah (2004) suggested five principles for designing chemistry visualisation tools: (a) providing multiple representations and descriptions, (b) making linked referential connections visible, (c) presenting the dynamic and interactive nature of chemistry, (d) promoting the transformation between two dimensional and three dimensional, and (e) reducing cognitive load by making information explicit.

H_2O

Empirical formula | Ball-and-stick model | Structural formula

Figure 3. An example of multiple representations of a water molecule using CMM software

Computerised molecular modelling (CMM) is a tool for representing simple and complex molecular structures that has increasingly been made available to students as computer graphics technology evolved and became more affordable. As Figure

3 shows, a molecule can be represented in multiple ways, providing various aspects and engaging students in modelling activities. As the complexity of the molecule increases, so does the benefit of viewing it via different model representations and developing modelling skill especially important for chemists. The advantages of using CMM in the classroom are that each type of representation has its unique features: structural formula representations provide for examining each atom and bond type in the molecule but disregard their relative volume. Ball-and-stick representations account for atom volume but not 3D structure. Finally, space filling models provide a 3D holistic picture of the molecule, but do not enable to inspect individual atoms and bonds.

Incorporation of CMM into chemistry courses has been found to foster students' understanding of 3D molecular structure, spatial ability, modelling skill, and meaningful learning (Barnea & Dori, 1999; Donovan & Nakhleh, 2001; Dori & Kaberman, 2012). Despite the prevalent use of CMM in biological and chemical research and recognition of its contribution to chemistry learning, practice of CMM in undergraduate and high-school courses still remains limited.

Data presentation involving ICT can be determined by different agents and take on many forms. For example, in terms of variety of presentation forms, it can involve several types of multimedia. In terms of determining agents, the presented data can be predetermined by software developers, co-constructed, or constructed solely by the learners.

Animated visuals in chemistry teaching

More commonly, the use of ICT in chemistry teaching and learning takes the form of pre-designed animated visual e-material in an attempt to help learners make links between the macroscopic, submicroscopic, and symbolic elements in science (see Chapter 4). Students are thought to build mental representations of multimedia instructions (Mayer & Chandler, 2001). It has been argued that changing presentation format can reduce unnecessary memory load (Sweller, van Merriënboer, & Pass, 1998). Another advantage of the animated visual e-material lies in its capacity to help demonstrate the dynamic nature of activity at the submicroscopic level (Eilks et al., 2010; Ng, 2010) and reduce the emergence of alternative conceptions or misconceptions which are related to basic chemical principles (Yang, Greenbowe, & Andre, 2004).

However, researchers have identified challenges with regard to the realization of animated visual e-material potential. Ploetzner, Bodemer, and Neudert (2008) argued that the high transfer rate could limit attention span, and Huk (2007) suggested that challenges existed with regard to spatial relations. Mayer and Chandler (2001) as well as Rodrigues and Gvozdenko (2011) pointed out that particular simulation designs may affect learner information processing capabilities, and that their use by students might reflect their e-learning skills rather than their science subject skills and conceptual understanding. Other researchers also report on factors that may impede chemistry where animations and simulations were involved. For example, Schwartz, Andersen, Hong, Howard, and McGee

(2004) and Azevedo (2004) suggested that students may develop inadequate meta-cognitive competencies, while Huk (2007) noted that their use may also result in limited ability of recognizing spatial relations properly or using them adequately.

Beyond this point, Eilks et al. (2009, 2010) emphasized that many visualisations found in the Internet mirror commonly known misconceptions held by many students (see Chapter 4). Those misleading visualisations might even hinder effective learning of scientifically sound concepts because they are sometimes inaccurate or even in contradiction to the intended learning outcome. That means the teacher should very carefully select visualisations from the Internet and determine whether the visualisation is sound and appropriate for the intended learning goals. Also the teacher should be very reflective if designing visualisations by him or herself.

Interactive whiteboards in chemistry teaching

Interactive whiteboard technology (a computer linked to a projector enabling a large interactive display) has gained prominence in recent years. Betcher and Lee (2009) have argued that it can bring a range of ICTs together to form a part of classroom practice, and in so doing, positively influence learning by enhancing interactivity between the resource, the students, and the teacher. Murcia (2010) has suggested that interactive whiteboards provide visually-enhanced multimodal presentations and encourage communication in teaching and learning environments. Murcia (2010) argues that students need to experience multiple representations in the classroom and that interactive whiteboard technology provides an opportunity to address this requirement. It has been argued that interactive whiteboards could facilitate active engagement in school science, linked to contemporary real world science through Internet-based technologies.

There is little research evidence to confirm the potential of interactive whiteboards in supporting learning in chemistry, but there is evidence suggesting that interactive whiteboard potential can be realized. Hennessy, Deaney, Ruthven, and Winterbottom (2007) found that teachers exploited the dynamic and manipulative nature of whiteboard technology in order to "*focus thinking on key scientific concepts and processes, to unpack, explain and organically build them up and to negotiate new, shared understandings*" (p. 297). Higgins, Beauchamp, and Miller (2007) reviewed the literature on interactive whiteboards and suggested that while using whiteboards, "*interactivity is most effectively sustained through effective questioning as well as a wider range of activities*" (p. 216).

Sensors, data collection, analysis, and communication

Sensors and data collectors complement the data generating phase in modern student-oriented learning approaches like inquiry learning (see Chapter 6), and case-based computerized laboratories (Dori & Sasson, 2008). Although research results prove this technology to be very promising in different terms of supporting the process of learning, it still is not standard in everyday classroom practice.

A sensor is a device that produces a measurable response to a physical or chemical change in a system like temperature, motion, sound, light, pressure, volume, pH, or concentration. A data collector receives and processes these changes so that it is computable. This system is generally complemented by a system that calculates and visualises the data in real-time as a table or a graph. In research literature, the term real-time graphing is often used for such a system (Dori & Sasson, 2008). Older terms for this approach are MBL – (Lavonen, Aksela, Juuti, & Meisalo, 2003) and, in the UK, the system is often dubbed as data loggers and data logging sensors (The University of York Science Education Group, 2002).

Current systems used in classroom practice differ in the way data is processed and visualised. The most common has been a microcomputer, but also modern graphic calculators used in mathematics education can also be connected via an interface to sensors. A third type is a hand-held device that combines the data logging, computing, and visualising procedures. The last two options are more flexible to use, enabling data to also be collected in the field.

Using sensors obviously leads to accurate measurements. The user can collect data in a shorter period of time and present it in a more meaningful format. But beyond this, the promise of the technology is to enhance the output of the practical work. It should be more than a lab session involving simply collecting data and making graphs. Having the chance to perform more experiments in the same amount of time compared to traditional experimentation, enables the deeper understanding of data and graphs by discussing and interpreting both and connecting them to the phenomena and the underlying chemical concepts. Given the pace at which technology moves, it is not surprising that the last decade has seen significant increase in the use of ICT for just-in-time data collection to enable fine grained analysis, and to reduce the monotony often associated with data collection.

There is a body of literature documenting research on the use of sensors and data collectors in data generation within current student-oriented learning approaches. Sensors produce quantifiable responses while data collectors accept and process these responses to enable them to be able to be gauged. There is evidence that the use of sensors and data collectors can offer opportunities for students to learn chemical concepts and to understand chemical processes. For example, the term real-time graphing indicates a key feature of the technology, as students get immediate access to their measurements. Brasell (1987) showed that a delay of only 20-30 seconds in displaying the graphed data inhibited nearly all of the learning of students. Students getting the data these few seconds later already appeared to be less motivated, less actively engaged, less eager to experiment, and more concerned with procedural than conceptual issues. However, there are some disagreements among researchers, some claim that having software construct graphs in an appropriate format could lower the students' engagement in understanding them and so prevent them from acquiring graph constructing and interpreting skills (Beichner, 1990). Most of the software supporting the systems allow more ways of representing the data, enabling the learner to make the decision about the appropriate format. Friedler, Nachmias, and Linn (1990) argued that using a computer to collect and represent data might reduce the load on students' working memory and free them for observation and interpretation. Apart from the real-time effect, the flexibility of the technology promises to be a key element in supporting inquiry or discovery learning approaches, where students are asked to design experiments, collect and analyse data, and communicate and debate findings and ideas in small groups over a longer period of time (Bell, Urhahne, Schanze, & Ploetzner, 2010)

Another aspect was researched by Nakhleh and Krajcik (1994). They compared three groups of 11th grade chemistry students performing acid-base titrations. Within each group, students individually conducted the same set of titrations using different technologies: chemical indicators, pH meters, and MBL. The students were interviewed before and after the titration and concept maps were constructed from the propositions the students used in the interview. Comparing and analysing these maps, Nakhleh and Krajcik (1994) identified that the "*students using MBL exhibited a larger shift in their concept map scores, which indicates a greater differentiation and integration of their knowledge in acids and bases*" (p. 1077). In another study, Dori and Sasson (2008) tested a case-based computerized laboratory with 12th grade high school students. The learning environment integrates computerized experiments with emphasis on scientific inquiry skill and comprehension of case studies. Compared with students that learned in a traditional learning environment, the experimental group students improved their chemistry understanding and graphing skills. The researchers showed that using data loggers and sensors in chemistry lessons could help promote higher-order thinking skills and provided students with the opportunity to interpret graphs that are produced while they observed the activity. This enables students to compare and relate the real time graph to a graph generated from a theoretical model and fit in with constructivist approaches to learning. Graphs obtained with the use of data loggers during an MBL experiment can encourage data analysis by helping students to relate it to a graph generated by a theoretical model (Rodrigues, Pearce, & Livett, 2001). It has been shown that deeper understanding of acid and base chemistry was possible when students were engaged in contextual student-centred activity while emphasizing their inquiry skills. MBL supports the development of conceptual understanding. The work by Lavonen et al. (2003) suggested that a user-friendly MBL should be versatile, based on 'plug and play' with easy set-up and data collection modes. However, it has also been argued that the use of data loggers alone does not result in better learning, since there is also a need for informed consideration of pedagogy.

In terms of data collection and analysis, with the growing availability of the Internet, students have access to information of a chemical nature. Making informed judgments and being able to analyze the veracity of this information is a key skill. While the advantage of Web-based data lies in its capacity to provide flexible learning opportunity and independent research anytime, anyplace and anywhere (Ng, 2010), the learner can also be misinformed. If Web-based resources are to encourage understanding, it is necessary to have developed 'search and assess' inquiry skills, that enable information at one site to be critically analyzed before another search is undertaken (Hoffman, Wu, Krajcik, & Soloway, 2003).

Use of the World Wide Web in chemistry teaching

As Murray-Rust, Rzepa, Tyrrell and Zhang (2004) stated many people now see the Internet as their first port of call when looking for information. In a recent conversation with Sugata Mitra he suggested that there was a popular myth that the Internet contained erroneous information. He suggested that it was actually (if you ignore politics and religion) a self correcting mechanism that by at large contained fairly accurate information. As a consequence he would work with young primary aged children in school classes and pose questions such as "How did the world start and how will it end?" and leave them to make the case by researching, often through access to the Internet. Or, if they are studying history, he'd post a question, like, "The British Raj was it a good or bad?" The point is that the nature of questions he posed did not rely on simply seeking out 'factual' information, but on interpreting information that was available and making an informed decision.

Given the body of chemistry facts available on the Internet, it should now be possible for teachers to pose questions that required their students to use the Internet to access that information through application rather than simply recall it. These activities necessitate the development of transfer skills, which in essence are the skills needed to adapt and apply knowledge and skills in changing situations (Sasson & Dori, 2012). The body of information available is growing at a rate of knots, and to simply expect students to recall bodies of information is no longer necessary. Chemists, chemistry teachers, and chemistry students need to do more than simply be able to recall vast bodies of knowledge, we need to be able to reason, think critically, solve problems and make decisions, all of which become more doable if we involve the Internet. As part of our role as chemistry educators we need to ensure that students can access and use data sources in a meaningful way, and the Internet allows for this type of activity. As Murray-Rust et al. (2004) suggest, the Internet has become an integral part of the scientific process, through establishing data quality, allowing for validation, enabling access and reuseability, promoting comprehensiveness, encouraging metadata inclusion, increasing scale and power, enabling distribution and permanency and convenience. It is therefore surely right that schools use the available ICT, in this case the Internet to model and replicate the practice seen in the working scientific community.

Stojkovic and Kostic (2009) suggested another advantage in using the Internet as a range of multimedia (Text, video, audio), which may suit different learners. Although most of the students have access to the Internet and are used to it in everyday life situations (like searching for favourite music or information about celebrities etc.) it does not guarantee success, when using it for inquiry in chemistry. In such domain specific tasks, students have less expertise and need specific competencies, like developing a strategy to find and evaluate relevant scientific information, valuing the usefulness and relevance of information for the learning process, deciding the range and depth of information required, and deciding how to represent the information adequately (Witteck, Most, Leerhoff, & Eilks, 2004). Witteck et al. (2004) and Frailich et al. (2009) suggested (a) to use the internet in collaborative learning scenarios rather than individual (see Chapter 7) and (b) to provide scaffolds or prompts about the objectives of the task. Examples for this kind of guided use of the internet are WebQuests (e.g. www.WebQuest.org). Here the teacher can give support based on the experience of the learners, prepare co-operative or collaborative tasks, or provide web-sites as examples of good practice.

What do future ICT skills in chemistry entail?

The work described in this chapter pertains to two target populations: (a) individuals expected to become thoughtful citizens in a science and technology-oriented society, and (b) individuals planning to choose a career in science education (see Chapter 1). Throughout their life and career, these individuals will be required to ask critical questions, seek for answers, make valid decisions, acquire new ICT skills, and become life-long learners. Therefore, it is important to develop students' ability to pose questions, engage in critical thinking, and be autonomous learners especially using ICT.

Technological breakthroughs are hard to predict and todays cutting-edge technologies could quickly become absolute tomorrow. For example, a decade ago, Hollingworth (2003) identified familiarity with using CD-ROMs as a key ICT skill. About five years later, this is no longer a very prevalent means for dissemination of information. Most laptops do not even have a CD-ROM drive, data is exchanged via flash drive, and wireless and storage technologies secure the future of cloud computing, with the basic tenet that information is stored somewhere on a server, available from any computer.

While we can expect ICT skills to become increasingly important, we cannot predict the development of future technologies or which of the current innovations will make its way. Teachers must therefore be able to follow the current developments and to adapt their teaching based on the changes. Aksela (2010) described this ability of the chemistry teacher as being lifelong research-oriented, an "*expert in teaching, studying and learning*" (p. 84) (see Chapter 10).

Many past studies focused on the learner and measured the impact of variables such as computer attitude, computer experience, or gender difference (Tondeur, Van Keer, van Braak, & Valcke, 2008). While results of such studies support evidence-based design of learning environments that use the power of ICT, they do not answer the question of how ICT gets more integrated in classroom practice. This is one key element for future research. Tondeur et al. (2008) indicated that major problems of integrating ICT in classrooms could be traced back to a disregard for ICT in school policy. School-related policies such as an ICT plan, ICT support, and ICT training, have a significant effect on class use of ICT. In addition to a pre- and in-service teaching curriculum that builds up competencies in the use of ICT, rethinking at the school policy level is necessary to give ICT more room in schools (Peled, Kali, & Dori, 2011).

Development of ICT related to chemistry teaching has to be considered in light of two main questions: (a) Learning *through* ICT: How can new technologies support chemistry learning and teaching?, and (b) Learning *to use* ICT: How does chemistry education prepare teachers to master chemistry-related ICT? (Webb, 2002).

A key argument for ICT use in chemistry is the potential to represent data in different modes. As interactive whiteboards become ever more prevalent in the classroom, teacher education should focus on integrating technology into the classroom rather than replacing the traditional technology, ensuring that value is indeed added, as advocated by Osborne and Hennessy (2003). Advanced classroom scenarios need to make use of this kind of interactive whiteboard software to exploit the potential of whole class interactive teaching and encourage students to share ideas and findings.

Collecting, analyzing and reporting data will still be a key competence in academic research or chemistry-related industrial businesses. Due to new developments there will be ongoing changes in the hardware in school or in businesses used to process and visualise the data. What has been the computer and is now a laptop can well be a tablet PC. But the use of data collectors and the knowledge to interpret the data still remains the same and will need to be adapted to the new technologies without much effort. Other chemistry-related ICT skills, including applications that support writing chemical formulae, drawing chemical structures in 2D or 3D format, or operating a laboratory apparatus are expected to evolve along with current technologies with no dramatic changes in how to use them.

The case for using ICT in its various forms for teaching and learning chemistry warrants further inspection. It is also worth considering the growing influence of social media on students and teachers, and to consider how these forms of technology could be used to support teaching and learning chemistry.

Employing ICT in classroom practice requires not just insight into the capacity of these technologies. There is also a need to consider how these technologies and tools inform the teachers' pedagogical content knowledge (PCK) and assessment knowledge (AK) in order for them to make informed use of ICT. Rodrigues (2010), Ng (2010), Fehring (2010), and Avargil, Herscovitz, and Dori (2012) reflect on how some of these issues can be addressed.

THE PRACTICE OF CHEMISTRY TEACHING

If properly designed, integration of instructional technology in the chemistry classrooms can potentially play an important role in acquiring learning skills. Merely using ICT in classroom practice does not guarantee success. The implementation has to be carefully prepared and guided by the teacher, who must ensure that the students had acquired basic knowledge in using the technology. The teacher must connect the task or research question to the procedure or experiment and use the mathematical concepts necessary to analyse and interpret the resulting graphs. In case of uncertainty or if the students' expertise is heterogeneous, the teacher has to provide adequate scaffolds.

In spite of the potential of ICT, its use in teaching science in general and chemistry in particular, in schools is still limited. Although we know ICT value, studies conducted at the beginning of this millennium reported that not many teachers use computers in the science classes or laboratories (Peled, Kali, & Dori, 2011). We must also distinguish between using ICT once or twice and integrating ICT as a regular teaching practice. One obstacle that an enthusiastic teacher must overcome is the lack of (up-to-date) tools in the laboratory. But even if a school is well-equipped, success is not guaranteed. The teachers need to be familiar not just with the tools and the software, but to also appreciate the pedagogical value of ICT. They need to know how the technology could help the students link the work done in the lab session to the understanding of chemical concepts. Otherwise the teachers might believe that data logging is encouraged for the sake of introducing ICT into science practical work, even when conventional techniques are equally or more appropriate (see The University of York Science Education Group, 2002). Therefore pre-service or in-service training plays a key role in getting familiar with the technology.

ICT learning environments and pedagogical approaches

One of the major reasons for using ICT in teaching chemistry is the visualisation capability that allows teachers and students alike to present and view of chemical phenomena and processes via multiple representations (Dori & Kaberman, 2012).

For example, *WISE Science*, a Web-based inquiry program, enables teachers to incorporate inquiry projects into their instruction in a variety of ways (Slotta & Linn, 2009; Figure 4). Typically, teachers have students engaged in the project in pairs so that students can collaborate and build from one another's ideas. Using the WISE inquiry map on the left hand side of the screen, students interact with the inquiry projects at their own pace, with the ability to revise or return to previous parts of the projects and strengthen explanations, drawings, and models during the project.

While students are working on WISE projects, many teachers take the opportunity to have small group discussions with their students about important concepts or questions. These small pairings, along with the teacher technologies of WISE, enable teachers to gain insight into their students' understandings. WISE technologies enable teachers to see real-time progress and responses of their students within the project. While students are working on the project, teachers can see which students may not have understood a visualisation by looking at the related embedded assessment. These responses are collated by class, so a quick glance can help the teachers see which students may not have understood a concept and then the teacher can give targeted help to that student pair. Likewise, WISE

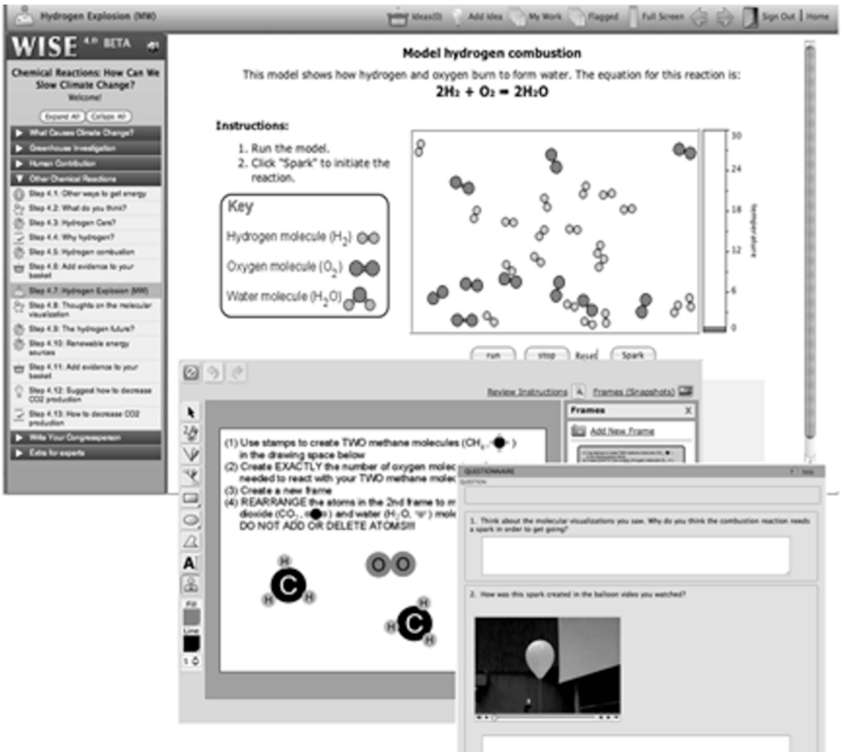


Figure 4. Web-based Inquiry Science Environment (WISE) with dynamic visualisations from Molecular Workbench

offers teaching and monitoring tools so that at a glance teachers can see which student pairs have completed what percentage of the project. If a teacher sees that a student pair is not keeping up with their classmates, the teacher can help that particular group. Teachers also use WISE to give feedback and grades to students during the project, typically done at the end of the day. WISE tools enables teachers to respond to student explanations and assessments by giving numerical scores, pre-made comments such as "*Nice work, but needs elaboration*," or create their own customized comments. Students immediately see the teacher feedback the next day when they log in to WISE and can then use the opportunity to revise their work (Slotta & Linn, 2009).

Another example is taken from the reformed chemistry curriculum in Israel and is focused on the laboratory unit (one of five) which includes in addition to hands-on inquiry-type experiments (Barnea, Dori, & Hofstein, 2010) also a case-based computerized laboratory and computerized molecular modelling (CCL & CMM) module (Dori et al., 2005; Kaberman & Dori, 2009). In the CCL & CMM module students are exposed to various representations of the same molecule (see Figure 5 and Table 1) while working with software packages such as the *ISIS-draw* and *WebLab Viewer*. In Table 1 and the text that follows we explain how to use the CMM and design assignments for students.

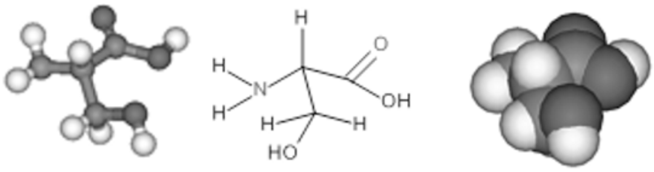
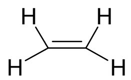
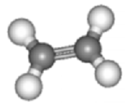
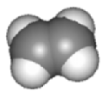
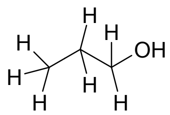
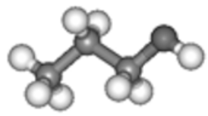
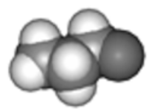
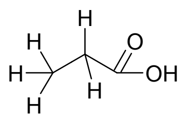
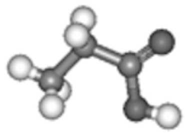
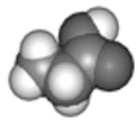


Figure 5. Molecular representations of serine amino acid – $C_3H_7O_3N$

Table 1. A variety of molecular representations of ethylene, propanol, and propanoic acid

	Molecular formula	***Structural formula***	***Ball-and-stick model***	***Space-filling 3D model***
Ethylene (ethene)	C_2H_4			
Propanol	C_3H_8O			
Propanoic acid	$C_3H_6O_2$			

In the chemistry classroom, the teacher can provide the students with the names and molecular formula (columns 1 & 2 in Table 1) and ask them to use the CMM software for drawing structural formula, ball-and-stick, and 3D models (columns 3, 4 & 5 in Table 1) for each one of the compounds. Another option is to submit a similar table with blanks (empty cells) in various rows and columns and ask the students to fill the missing cells. For example, give the molecular formula and 3D model of propanoic acid but leave blanks in the columns of compound name, structural formula, and ball-and-stick model.

Using audience participation software and interactive whiteboards

The program *Who wants to be a millionaire?* is probably globally well-known, either through a version in your country or through the film *Slumdog millionaire*. Contestants have an option, when they experience difficulty in answering a question. They can use an audience response system to collect responses from the audience through the 'Ask the audience' help facet. Audience response systems are being increasingly used in classrooms and lecture theatres, to both provide a more engaging and interactive option, and to provide the teacher/lecturer with instant feedback regarding current understanding within the cohort. Audience response systems are being used more frequently and integrated more effectively in learning environments to encourage participation because responses from the student cohort can be discussed with other students. The other advantages of an audience response system lie in the fact that they enable engagement with all students rather than hearing only the responses from the most confident or the vocal. The confidentiality aspect is also an advantage as a less confident student may consider providing a response anonymously to be less inhibiting and it may allow for the less popular responses to also be heard. As such, these audience response systems can help staff and students see the level and depth of understanding held by the students. As such, these audience response systems provide a mechanism that is both practical and effective as a formative assessment tool (Rodrigues et al., 2010).

An example of use: In a recent lecture with 300 student teachers, we drew on chemistry questions from a recent national survey of achievement. Using the interactive whiteboard, and an audience response system we were able to collect information about student understanding of particular chemistry questions and determine their level of confidence in answering those chemistry questions. The audience response system collected and collated responses. The students in the lecture theatre were invited to respond to the question by pressing one button on their audience response key pad and their participation was taken as consent. They could, of course, simply not pressed a button and as such could opt out. The software collected the responses anonymously maintaining confidentiality and at the same time the software collated the student cohort responses and generated graphs which were portrayed on the interactive whiteboard. These graphs depicted response patterns for each question. Within the lecture, these graphs and responses were then shared and discussed with the student cohort.

Table 2 identifies the chemistry questions that were posed in terms of (a) the school curriculum level (in this case, the Scottish 5-14 curriculum, where level A is the lowest level and aimed at a 5 year old, while level F is the highest level aimed at the 13 and 14 year old child); (b) topic/area of chemistry; (c) a shrunken version of Bloom's taxonomy (see Chapter 2) was used to classify the question (for example in terms of it relying on recalling information, or a question that asked students to apply what they knew). The first column in Table 2 shows the percentage of our sample cohort that pressed the right button for that particular question. So, for example, 27.4% of the cohort got the question on the candle flame correct, whereas 84.5% of the sample cohort got the question on states of matter correct. Both were on changes of state, in essence, but one was a recall question aimed at a lower curriculum level and the other a comprehension question at a slightly higher curriculum level.

Table 2. Responses to the chemistry questions

% Correct	*Curriculum 5-14 Level*	*Topic/area*	*Shrunken taxonomic scale*
27.4	Level D	Candle flame	Comprehension
6.4	Level C	Boiling water	Apply
84.5	Level C	States of matter	Recall
65.8	Level E	Reactivity series	Apply
30.8	Level F	Chemical reaction	Apply
57.0	Level E	pH	Comprehension/Recall
34.9	Level F	Atomic mass	Apply

In the lecture, using the audience response system, the question on states of matter was answered correctly by nearly 84.5% of the cohort. The question was: A substance has a fixed volume but its shape depends on the container. What is this statement referring to?
– Solid
– Liquid
– Gas

In the Scottish 5-14 curriculum guidelines, the topic is found at Level C (attainable in the course of primary 4 to primary 6 (age 8-10) by most students). During the lecture, the high rate student cohort suggested that their high correct rate was possibly because it was an easy question. They were familiar with pouring liquids from different vessels in their everyday life. They said this enabled them to recall and answer the question. In contrast, the question on a burning candle, which we assumed would be familiar to student teachers, showed that less than 30% were able to correctly answer the question. The question was: When a candle burns...
– The wick burns
– The wax vapour burns
– The wick and the wax vapour both burn
– The wax melts to let the wick burn

Three of the responses are acceptable, though in terms of the comprehensiveness/fullness the response some are better responses. From a science perspective, the most comprehensive response is ‘The wick and the wax vapour both burn.’ But the question did not ask students for the most comprehensive answer, something that was voiced by the student cohort during the discussion. As a result, the response range suggests that the students had identified acceptable responses rather than opting for the most comprehensive one. This level of understanding of the student teacher response is invaluable, for it helps identify whether the difficulty lies with the respondent’s understanding of the chemistry, or the respondents understanding of the question. As such, the use of audience response systems with large cohorts, provides a mechanism that enables educators (and the participants) to see what other people think, while remaining anonymous, and affords an opportunity to share reasons for particular patterns of response. For more details on the use of an audience response system, see Rodrigues et al. (2010).

Using sensors and data collectors

A common use of sensors and data collectors is to understand the concept of acids, bases, and neutralisation by analysing a titration. While titrating e.g. 20.00 ml of a weak acid (a solution of acetic acid, 0.1 M), with a solution of sodium hydroxide (0.1 M) by using an adequate indicator, without access to data collectors and a computer the students only will receive one piece of information: the equivalence point. By using different sensors (pH, conductivity, meter or temperature sensor), students get a lot of information about the whole process, serving as evidence for the whole concept of acid-base processes. Figure 6 shows the temperature and pH profile of this titration. The neutralisation is an exothermic process indicated by the rising temperature until the equivalence point is reached. Beyond the equivalence point, less hydronium-ions are in the solution to be neutralized and in an open system the permanent heat dissipation to the surrounding area will cool down the system.

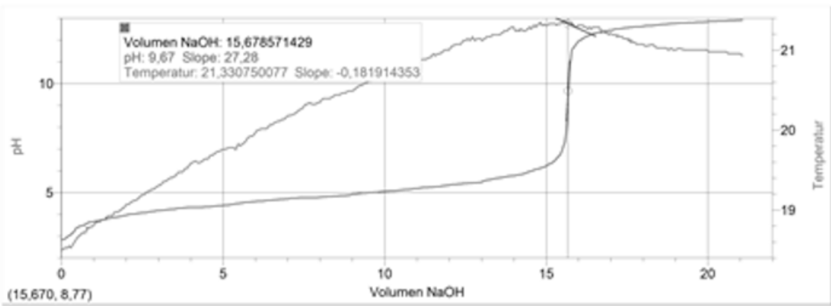


Figure 6. Titration of acetic acid with sodium hydroxide solution, measuring temperature and pH against the volume of the sodium hydroxide solution

Figure 7 shows the conductivity of the system depending on the added amount of alkaline solution. The profile can be explained by the fact that different kinds of ions have a different velocity of migration in liquids. After the equivalence point, less hydroxide ions are neutralized by hydronium-ions. Both kinds of ions support the conductivity of the solution better than the other ions (like in the example of the sodium or acetic anions).

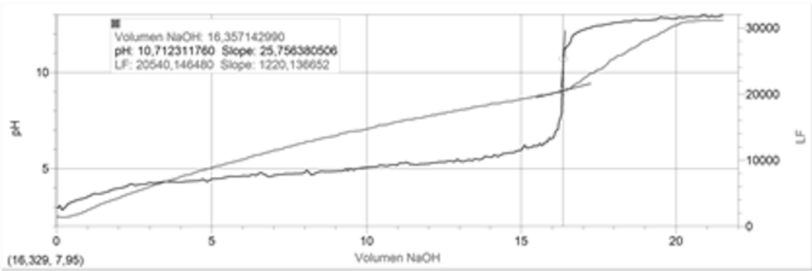


Figure 7. Titration of acetic acid with sodium hydroxide solution, measuring conductivity and pH against the volume of the sodium hydroxide solution

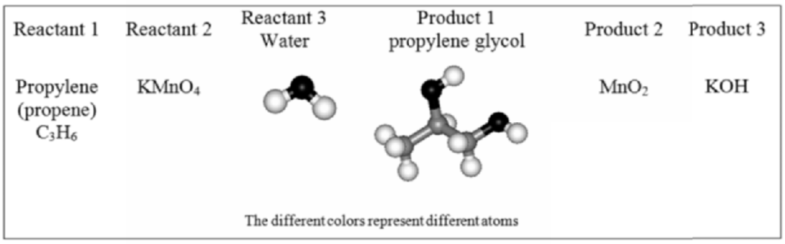
SUMMARY: KEY SENTENCES

- Information and communication technology (ICT) is a general term that includes integration of virtual models, simulations, and dynamic visualisations as well as information transfer, and data collection. This term can include various forms of technology driven processing, communication, presentation, and application devices (e.g., television, radio, telephones, and computers).
- The dual-coding theory emphasizes the integration of visual and verbal models within ICT for participation in active learning more efficiently.
- Visualizations such as computerized molecular modelling foster conceptual understanding, modelling skills, and transfer among multiple representations.
- Utilization of computers and sensors in chemistry classrooms for collection and analysis of data may help strengthen students' graphing and problem solving skills.
- ICT may help in creating learning communities, designing learning environments, and improving students' meaningful learning.

ASK YOURSELF

1. Web-based periodic table vs. paper-based periodic table
   - Design two types of student activities that make use of a web-based periodic table.
   - Design two types of student activities that make use of a paper-based periodic table.
   - List advantages and disadvantages of the web-based and paper-based periodic tables.

2. Simulations of a titration wet laboratory task
   – List the benefits and disadvantages of using a wet lab acid base titration vs. a simulation of the same experiment.
   – Identify the issues you would need to consider when teaching acid base titration in a computerized learning environments and encouraging students to use variety of sensors to collect their data.
   – Write the instructions you would need to give students for enabling them to use a particular website while visualizing multiple model representations of molecules.
   – What are the likely difficulties students may encounter when using a particular wet laboratory, with and without automatic data collection and sensors? How can you best reduce these?
3. CMM activity (based on Dori & Kaberman, 2012)



   – Pretend you are a low achieving student: Write a chemical reaction for propylene glycol production based on the figure above.
   – Pretend you are a high achieving student: Write a chemical reaction for propylene glycol production using two or three chemistry understanding levels: macroscopic, submicroscopic, symbol, and process.

In this example, the students are required to describe the full process in text (*process level)* as well as with a balanced equation (*symbol level*). If they also refer to the new bonds that were constructed or the functional groups in each molecule they present their knowledge also in the *micro-/submicro level*.

   – You were asked to write responses of both low and high achieving students to the following assignment: (a) Using the chemical reaction for propylene glycol production, write the molecular and structural formula of product 1. [Transfer from a 3D model to molecular and structural formula]. (b) Draw a model for reactant 1. [Transfer from molecular formula to a 3D model drawing].
   – Design a rubric to assess the students' responses to all the assignments above (1-3) while using CMM. Based your rubric on chemistry understanding levels, model accuracy, and the ability to transfer among the various representations.

HINTS FOR FURTHER READING

Voogt, J., & Knezek, G (eds.) (2008). *International handbook of information technology in primary and secondary education*. Dordrecht Springer. This handbook gives an overview about foundations, potentials, barriers and opportunities for the use of ICT in education from the point of view of general education.

Songer, N. B. (2007). Digital resources versus cognitive tools: A discussion of learning science with technology. In S. K. Abell & N. G. Lederman (eds.), *Handbook of research on science education*. Mahwah: Lawrence Erlbaum. Songer gives and overview about different types of software and their potential use in science education.

Rodrigues, S. (ed.) (2010). *Multiple literacy and science education*. Hershey: IGI Global. This book explores various perspectives and examples of using ICT in the science classroom. The book allows insights into current research, practices, and proven approaches towards development of better multiple literacy teaching environments in science education.

Gilbert, J. K., Reiner, M., & Nakleh, M. B. (eds.) (2008). *Visualization: Theory and practice in science education*. Dordrecht: Springer. The book mirrors perspectives of scientists, science education researchers, computer specialists, and cognitive scientists, on the use of pictures, diagrams, graphs, and concrete models in science teaching.

Dori, Y. J., Barak, M., Herscovitz, O., & Carmi, M. (2005). Preparing pre- and in-service teachers to teach high school science with technology. In C. Vrasidas & G. V. Glass (eds.), *Preparing teachers to teach with technology*, 2nd volume (pp. 303-321). Greenwich: Information Age. The chapter provides ideas of how to educate teachers for the effective use of ICT in science education.

Luehmann, A., & Frink, J. (2012). Web 2.0 technologies, new media literacies and science education: Exploring the potential to reform. In B. J. Fraser, K. Tobin & C. J. McRobbie (eds.), *Second international handbook of science education* (pp. 823-837). Dordrecht: Springer. The authors discuss – starting from two vignettes – the upcoming potential of Web 2.0 technologies for reform in science education, e.g. the case of using blogging technologies in science education.

RESOURCES FROM THE INTERNET

RSC: pubs.rsc.org/en/content/articlelanding/2004/ob/b410732b. P Murray, H. S. Rust, S. Rzepa, M. Tyrrell and Y. Zhang describe representation and use of chemistry in the global electronic age.

The RSC Learn Chemistry platform: www.rsc.org/learn-chemistry. The Learn Chemistry website offers access to hundreds of resources for chemistry education in the Internet.

The Globe project: Globe.gov. ICT is used to form a worldwide network of students, teachers, and scientists working together to study and understand the global environment.

WISE Science: wise.berkeley.edu. This website offers students in grades 5-12 an exciting and engaging learning environment in which they can analyze and examine up-to-date scientific controversies.

Co-Lab: www.co-lab.nl. The EU-funded Co-Lab (Collaborative Laboratories for Europe) project creates ICT-based learning environment to develop flexible knowledge in science domains, skills to collect and synthesise information, and to collaborate with others. It includes facilities for experimentation, collaboration, and domain modelling.

CoRelect: www.coreflect.org. The EU-funded project CoReflect promotes problem-based innovative inquiry learning environments based on the STOCHASMOS web-based teaching and learning platform for reflection on socio-scientific debates.

YouTube: www.youtube.com/watch?v=F0nBWGCwbPM&list=UUvJpiRJGEfETXudAYGnsbfQ&index=1&feature=plcp. A video presents an example of a primary-secondary science teacher professional development project in which participants from six schools produced podcasts for each school separately.

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RICHARD K. COLL, JOHN K. GILBERT, ALBERT PILOT &
SABINE STRELLER

9. HOW TO BENEFIT FROM THE INFORMAL AND INTERDISCIPLINARY DIMENSION OF CHEMISTRY IN TEACHING

Traditional research on chemistry teaching and learning is dominated by the context of formal, often compulsory, schooling. There is, however, growing interest in learning outside formal educational contexts, and the interface between formal and informal learning. The literature suggests that chemistry teaching commonly fails to recognize or exploit the interdisciplinary nature of chemistry, that is, how chemistry – although a distinct subject or discipline of inquiry – contributes to other disciplines such as the biological sciences. As a consequence, chemistry teaching that is subject-bound may fail to reflect the way chemistry influences everyday life, and how it is used in the practice of scientific research and commerce more broadly. In this chapter we consider how teachers might benefit from the use of informal learning opportunities, and how chemistry teaching can take cognisance of the interdisciplinary nature of chemistry; as we shall see, the use of informal learning opportunities frequently inherently recognizes this interdisciplinary dimension of chemistry. We begin by unpacking the term 'informal learning' before exploring our understanding of the informal and interdisciplinary nature of chemistry.

THEORETICAL BASIS

The teacher, an experienced female primary school teacher, had not taken the class to a science museum before, and the visit was seen by the teacher to be predominantly for entertainment and fun. 'They have been really good lately and we have not been anywhere this term. I always like to take them somewhere each term.' She had no particular expectations for the visit, seeing it as a chance for the children to 'go and see things, materials, reactions and instruments that they haven't seen before.'
Vignette from New Zealand

Conceptualising non-formal and informal learning

According to Stocklmayer, Rennie & Gilbert (2010) for young people of below the minimum school-leaving age, the *formal* education and *informal* systems may be broadly characterised in the way set out in Table 1.

I. Eilks and A. Hofstein (eds.), Teaching Chemistry – A Studybook, 241–268.

Table 1. Characteristics of formal and informal education sectors

Education in the compulsory, formal sector is characterised by:

- Being involuntary (i.e. students are required to attend),
- Providing students with very limited choices, if any, of what and when they study,
- Often providing instruction that is by transmissive (didactic) methods,
- Often involving students working alone,
- Managed students in groups ('classes') that are homogeneous in age and attainment,
- Leading to the regular and rigorous assessment of what students have learnt, and
- Being under the close control of a teacher.

Education in the informal sector is characterised by:

- Being entirely voluntary as regards participation,
- Providing a wide choice of what can be studied, and when,
- Providing instruction in a wide variety of methods, few of which are transmissive,
- Enabling students to work either alone or in groups of their own choosing in terms of age and attainment,
- Only involving assessment, if any, that is for the immediate benefit of the student, and
- Not being under the close control of anybody with the role of 'teacher.'

The non-formal sector occupies positions intermediate between those of the formal and informal sectors (Figure 1). In particular, students make use of resources developed for the informal sector (e.g., museums, zoos), and are more able to work in groups and at their own pace (Hofstein & Rosenfeld, 1996).

Type	Characteristics			Example
Formal	School (attendance)	At school Out-of-school	Organised	Regular lessons at school A class visits a museum (organised by the teacher) a class visits the university for a project
Non-formal	Voluntary	Out-of-school and Free-choice	Organised	Summer school, science courses in the students' free time
Informal	Voluntary	Free-choice	Not organised	TV, visiting a zoo on Sunday

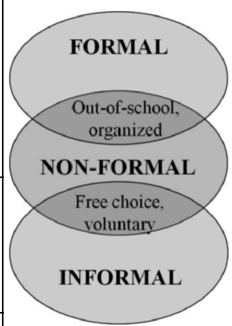

Figure 1. Types, characteristics and examples of learning

Traditional definitions of non-formal/informal learning. The field of informal science education (or out-of-school learning) has grown tremendously throughout the world in the past 20 years. Although the term informal learning is widely used, it is difficult to define what it means. In many cases, it is used simplistically to describe school events that take place outside school.

Informal learning, as described by Stocklmayer et al. (2010), actually includes conscious and unconscious forms of learning. Because such learning occurs outside formalized educational institutions, "*in most cases it is unplanned, casual, implicit, unintentional, at least not institutionally organised*," and thus consist of voluntary learning "*in immediate contexts of life and action*" (Rauschenbach et al., 2004, p. 29). In contrast, formal learning refers to forms of learning that takes place in formal institutions of an educational system like schools, or indeed post-compulsory education systems such as vocational training institutions, polytechnics, institutes of technology, and universities (Rauschenbach et al., 2004). Based on this definition, organised visits of school classes in student laboratories or science centres may strictly speaking not constitute informal learning (although places like zoos do see themselves as having a role in education; Figure 2), because such visits are school events that are not attended by the students voluntarily; they may then be seen as formal learning. However, there is seldom much structure to the learning in such visits, and students do often have choice about what they learn. For example, students visiting a zoo might have a broad learning objective (e.g., how is an animal enclosure designed to suit the needs of a particular species?), but can choose which animal to study. In addition to informal and formal learning, Rauschenbach et al. (2004) refers to 'non-formal learning,' which involves any form of organised education "*which is generally voluntary and features affordance*" (p. 29). That is to say, such learning opportunities are more readily available, and are not only available at set, prescribed, times. According to them only opportunities that are taken advantage during leisure time, like summer schools, should properly be considered to be non-formal learning. In order to differentiate visits in science centres, museums, zoos, or out-of-school laboratories from normal everyday school life and make clear that they are "not really formal," the term out-of-school learning is gradually increasing in usage, even though these centres seek to foster learning.

Free-choice learning. Consistent with the views of Rauschenbach et al. (2004) that 'informal learning' should be seen as learning that occurs outside the context of formal or compulsory school learning, is the notion of 'free-choice learning.' A number of out of school sites such as zoos, museums and interactive science centers are sources of what has historically been classified as informal or flexible learning (Rennie & McClafferty, 1996). However, Dierking and Griffin (2001) suggest the more appropriate term is free choice learning. Free choice learning as seen here is then learning that is self-directed, voluntary, and rather than following a set curriculum, is guided by a learner's needs and interests (or at least some choice in this, see above).

Figure 2. Poster at a zoo, with an educational message about the habitat for white rhino

Learning experiences outside the classroom. A third way of conceptualizing informal learning is that of learning experiences outside the classroom (LEOTC). This simply refers to all learning activities that occur beyond the classroom or in formal educational learning environments. Interestingly, these activities are reported to be an important part of many science curricula (see e.g., Ministry of Education, 2009b) – in which case they differ from the definition of free-choice learning and out-of-school learning presented above. Some subjects such as environmental education are particularly appropriate for science learning involving the outdoor environment (Green Communities, 2011; Eshach, 2007; Wilton, 2000). The link to schooling is further strengthened in some cases by the provision of funding to support links between schools and LEOTC sites (e.g., Ministry of Education, 2009a). Most common are field trips – something ostensibly highly valued by teachers and schools (Jordan & Strathdee, 1998). Certainly many such sites see themselves as involved in education (see above, and Figure 2), of public visitors and planned school educational visits (Coll, Tofield, Vyle, & Bolstad, 2003). Indeed, there are reports of upwards of 150,000 teachers in the US alone teaching science in such environments (St. John, Dickey, Hirabayashi, & Huntwork, 1994).

There is a growing body of international research on the use of visits to informal science learning environments, as a means to enhance school science education. Hence, even if researchers conceptualize LEOTC, free-choice learning and informal learning as voluntary and learner driven, education officials worldwide see merit in the utilization of what might be seen as voluntary learning sites, and linking these to curriculum. Indeed, a special issue of the *International Journal of Science Education* (1991, vol. 13, no. 5) was devoted to research on 'informal sources for learning science.' A more recent review described 141 studies that have investigated various learning outcomes from science centre visits, including those relating specifically to visiting school groups (Rennie & McClafferty, 1996). The literature suggests that these visits can provide valuable, particularly motivational, opportunities for students to learn science.

Practical examples of non-formal and informal learning

It seems then from the literature that learning need not be confined to the classroom and traditional educational approaches that comprise compulsory schooling, and that useful learning may occur in unexpected places involving informal and non-formal learning processes. It is therefore of interest to consider what we know about learning practice in specific informal and non-formal learning contexts. Here we present examples of practice, which range from conventional sources such as museums and zoos, via mass media, to industrial settings and work-integrated learning. As we shall see the way learners interact with such sources of informal learning varies enormously, and in many case little is known from research about how learning occurs, or how it might be facilitated.

Museums and science centres. Traditional museums contain static exhibits of objects, grouped together in a distribution based on purpose, or spatial and temporal distribution. The visitor acquires factual information within a narrative of some kind (Rennie & McClafferty, 2002); the 'interactive exhibit,' on the other hand, requires mental decision and physical action by the visitor, which leads to a response from the exhibit (Rennie & McClafferty, 1996). Interactive exhibits were once grouped together in 'science centres,' but now they are also commonly incorporated into traditional museums. Interactive exhibits allow learning and having fun to occur at the same time. They are often the stimulus for later and more detailed learning, but such learning is unpredictable and therefore difficult to measure (Rennie, 2007). Hofstein, Bybee, and Legro (1997) note that education standards can be used to link formal and informal science education.

Static exhibits about chemistry in museums are usually examples of substances and animated displays of chemical processes. The range of interactive exhibits on chemical themes also is limited, sometimes because of safety, because they have to respond quickly to a visitor's actions and chemical reactions are typically either very slow or very fast. The change in an exhibit when action is taken by the visitor has to be visually dramatic, a requirement rarely met in chemical phenomena. Such exhibits also have to be physically robust and cheap to maintain. However, chemical apparatus tends to be fragile and chemicals are often expensive. For these reasons, the way that chemical inquiry takes place (see Chapter 6), as well as the social and environmental implications of chemical technologies, are commonly under-represented even in modern interactive exhibits.

Newspapers and magazines. Most newspapers carry articles on scientific and technological themes, either occasionally or on a regular basis, best written by journalists who have a background in science but this is not always possible. An individual journalist's professional standing will depend on getting articles published. This is a competitive environment, and the likelihood of publication of any article is highly dependent on the perceived ‘news value’ of an article (i.e., the likelihood that the readership of the newspaper will find it interesting). This might, however, give rise to curiosity by the student to explore the topic or issue using other sources (e.g., the Internet).

Although chemistry leads to innumerable products that are widely used and valued by the public, these tend not to get commented on in the press. Rather, attention is focused on the things that go wrong, for example, when the use of such substances leads to pollution. A focus on environmental chemistry should redress the balance somewhat, for such material could be presented with a balance between positive and negative slants, and within contexts that are of current interest to individuals and communities. At the same time, newspapers seem more inclined to report an overall picture, than to point to the caveats that framed the original science. They are also accused of sensationalism, whereby specific aspects of stories are overstated, for example, the scientific certainty of what has been discovered or produced, the implications and applications of discoveries, the nature of any controversies involved and, lastly, perhaps most importantly, any risks involved. For these reasons, newspapers have a limited use in disseminating an awareness of chemical ideas, especially of the applications and implications associated with them.

There are few magazines with a science/technology focus (at least in Western or English-speaking contexts): ‘New Scientist,’ ‘Scientific American,’ and ‘Forum’ stand out. Whilst articles with a chemistry focus do appear regularly in such magazines, only the USA-based Chemical Heritage Foundation produces magazines with a distinctively chemistry focus. Magazines in general do seem to give a somewhat more balanced treatment of chemical topics, especially of the applications and implications.

Popular books. ‘Popular science’ books are not textbooks, but are rather intended to provide entertainment as well as some education. They are continuously available in multiple commercial outlets (e.g., bookshops, railway stations, supermarkets). They deal with topics thought to be of such an immediate or potential interest to readers that they would be voluntarily purchased. As a genre, they have a number of attractions as an educational resource. They are flexible, in that the reader is able to pause for any length of time, reflect on what has been read, and re-read a section that has proved challenging or provoking of thought. They are capable of being structured so as to address a wide range of interconnecting themes, including an explanation of difficult and important scientific ideas, how these came to be discovered/invented, and the social implications of associated technologies. One great advantage of popular books is that they can include a wide range of representational forms (e.g., text, pictures, diagrams, instructions for practical activities), and can be accompanied by a CD, or links to the Internet.

There seems to have been no systematic study of the availability, use, and value of popular science books for chemistry education. In order to partially address this omission, a study of ‘informal chemistry’ books was recently undertaken (Afonso, 2010). Catalogues of publishers in English and Portuguese (both major international languages) were analysed, showing 131 chemistry-related titles and associated abstracts, which were placed in inductively-generated categories (Table 2). Because the purchase and use of all these types of books are a private matter, we know almost nothing about their educational significance. However, their sheer flexibility of form and content, along with their popularity suggests that they are of great potential significance for informal and non-formal chemical education.

Table 2. Informal chemistry books, inductive categorization of themes and presentation of ideas

Foundation ideas in chemistry	Here the core ideas of chemistry are presented so that they can be understood by a person without a background in the subject (e.g., by using extensive analogies based, wherever possible, on everyday experience).
History of developments in chemistry	Such books deal with how the subject of chemistry evolved.
Use of chemistry in other disciplinary fields	Chemical ideas are much involved in other disciplinary fields such as genetics, pharmacy, materials science.
Chemistry in everyday life	Such books deal with the way that chemistry contributes to everyday personal and social life, such as in cooking, the conduct of forensic science, and so on.
Science fiction with an emphasis on chemistry	These are books of fiction, including those about crime detection, making use of real or imaginary chemical ideas.
Chemical cookbook/ hands-on chemistry	These books present chemical reactions and phenomena that can safely be explored in the home.
Biographies of chemists	These books recount the contributions to chemistry made by individual chemists, often setting these against the background of the person's life trajectory.
Particular chemical elements, compounds and species	This broad category addresses the chemistry and implication of a particular substances and chemical species.

Radio. Radio broadcasting expanded greatly in the developed world during the 1920s, but then suffered an eclipse of public interest with the advent of television. The basic range of programme types with science content was, however, firmly established: inclusion in news programmes, science 'magazines,' dramas, documentaries. Radio has staged something of a come-back in recent years. The notion of 'narrow-casting' (i.e., focusing programmes on specific sub-sets of a population), has been introduced an addition to 'broad-casting.' This has been made possible by two developments. The first has been the cooption of the power of the computer, so that audio material can be added to otherwise-static websites that attract particular audiences. The second has been the drive to provide education for very large populations in developing countries (e.g., rural India), and for low density populations (e.g., in rural Australia). The publication of the book *Science in Radio Broadcasting* (Mazzonetto, Merzagora, & Tola, 2005) is a very helpful bringing-together of research into the role of radio as an informal source of science communication.

Radio has two distinct advantages as a medium of communication:

– The 'one-way' model of communication' (expert to the public) can be readily replaced or augmented by the 'interactive' model. In the latter, a scientist (here, a chemist) can directly discuss issues with an interviewer (the journalist). This readily enables scientific controversies to be addressed, especially those concerned with the implications and applications of new chemical discoveries and technological developments. The very recent and now-widespread use of the unfiltered 'phone-in' does enable members of the public, who feel that the interviewer and or the chemist is not being completely forthright, to bring issues into the open.
– The absence of visual images means that the listener has to concentrate on what is said in order to produce visualisations (mental models) of what is being presented. For some people, hearing is the preferred medium for learning, whilst the higher mental engagement that is required of all listeners will be generally supportive of the acquisition of knowledge and understanding.

The great advantage of radio is that it offers a wide range of roles for the expert – the chemist – in science communication. In summary, she/he can variously be presented as: "*a personality engaged in science, the author of scientific output, an involved commentator in the presentation, an objective provider of expert competence, a consultant to a programme's producers, both a producer and presenter*" (Mazzonetto et al., 2005, p. 60). This wide range of roles should do much to move the chemist to the centre of the chemistry communication process, provided that she/he is competent in the discharge of those roles.

There seem to be no reports of the value of radio specifically in the communication of chemical ideas. It is often asserted that the understanding of the inherently abstract nature of those ideas, where the molecule-level particle is the unit of understanding, requires verbal presentation to be accompanied by visual images (see Chapter 4). If the argument of Mazzonetto et al. (2005) about the focus of attention has merit, then radio could have explanatory potential for chemistry communication. In the light of the importance of addressing the social, environmental, and economic implications of the applications of chemical ideas, the capacity for bringing the informed scientist directly into 'contact' with the public does seem a great strength of the medium.

Films, TV, and video. Films, television programmes, and video recordings of both, may be thought of either as 'radio plus visual images,' or 'visual images plus audio commentary.' The range of types available is wide and the boundaries between types are blurred. Programmes specifically for school use are usually constrained within the curriculum, using the medium to present phenomena, experiences, experiments, that are not within the normal purview of the school science laboratory.

As regards adult audiences, films (also re-runs on TV, and video-clips of TV shows available on the Internet) are generally produced purely for entertainment, where the chemist, in particular, is normally portrayed as white, male and mad (Dalgety & Coll, 2004; Weingart, 2006), although recent programns like the CSI series out of the US, do portray chemsists in a more positive, albeit still eccentric, light. The material specifically intended for TV is one of three kinds. First, short inserts into news programmes; usually of chemical breakthroughs or of environmental disasters that are attributed to chemistry or chemical technology. Second, what Dingwall (2006) refer to as the 'blue chip' form; common examples being about wildlife or breakthroughs in science, where an authority gives an illustrated lecture. Excellent examples are provided by David Attenborough's numerous wildlife series. Third, what Dingwall (2006) refers to as the 'adventure' form, is where the presenter very visibly explores a phenomenon through practical activities. Steve Irwin's 'Crocodile Hunter' series in Australia and the 'Brainiac: Science Abuse' programmes in the UK are very disparate examples. Films with an overtly chemical theme seem few and far between.

Although Stocklmayer et al. (2010) observe that very little research into the effectiveness of such programmes has been undertaken, TV/video are regarded as an importance source of informal learning, perhaps because of the simultaneous use of images and sound (see Chapter 8). The medium is currently only exploited in respect of chemical ideas for the visualisation of abstract ideas (e.g., to show the mechanism of chemical reactions, or demonstrations of dramatic reactions on YouTube), and for overviews of complex chemical processes and manufacturing plants. The narrative aspect of the medium, its central virtue, is not currently exploited much, even though it would be most effective in respect of the applications and implications of chemistry and its technologies.

The Internet. The growth of computer-ownership and access to ever-more diverse web-pages has been exponential in recent years. In addition to text, the whole variety of visual images, from static to dynamic, can be included in any webpage (see Chapter 8). For students, the web is a source of non-formal information, whilst most adults have used it to find out about themes in which they are interested. For both groups, the greatest challenge is the development of evaluative criteria with which to judge, and hence filter, the huge range of material available on any topic, for there is almost no control over what is placed on the Web.

The video game enables the user to interact with a programme, albeit only to a limited and predefined extent. Beyond the receiver-only forms to website, interactive websites, such as YouTube, enable the individual to enter material thought to be of interest to others, and to comment on material already present. These variations no doubt make use of the ideas of science and specifically of chemistry: almost nothing is known about the extent and consequences of their use. Evaluative research into the educational use of video games in general seems sparse and generalised (Sandford & Williamson, 2005).

Social media and informal/non-formal learning. Since the large scale availability of the Internet, the learning environment for non-formal and informal learning has changed rapidly and dramatically. The use of digital media for communication and interaction has become in a short time a normal daily activity for most people. That development is particularly relevant for young people who have grown up in a digital age, and who likely cannot imagine a world without digital media. The traditional borders or the walls of the school, the library, museum and science centres may be seen by young people as something of an artefact from the past; related to a culture of the past. Non-formal and informal learning without digital media is now, and likely in the near future, seen by students as no longer relevant. This is not only just referring to the use of sources of information; it also refers to interaction among learners, and interaction between learners, teachers and experts. The production of paper-based resources (e.g., textbooks) is another important aspect of this change in the learning and teaching environment. Paper based resources traditionally were kept within the walls of the school or other institutions; nowadays publishing (e.g., via the Internet) has become common. An example of this is an inquiry-based chemistry module at secondary school in which the students in teams with a class do a study (e.g., bio-fuels), use the Internet for sources of information, interact in an Internet symposium involving peer review of their reports with classes in other places (including internationally), and publish the results on the Internet or in a national journal (Van Rens, Pilot, & Van der Schee, 2010). Production of paper-based resources and publishing these on a website was then only the first step; this is now accompanied by enriched productions of media such as videos, animations, interviews, and interactive facilities. It also is easier to copy, change, elaborate and use such material in other ways than traditional information (e.g., using Wikipedia and YouTube, but also scientific papers, reports and journals).

The Internet also is not mono-disciplinary. Chemistry in traditional learning is restricted to ‘chemistry,’ but this can better be conceived as an artefact of the old school world. In the real world chemistry, is always related to other disciplines like physics, biology, technology, economy, design, and is inherently related to daily life issues. Communication and interaction is much easier with email, SMS, Linked-In, Facebook, and other social media, making it normal for learners to initiate and maintain interactions with other learners, teachers and experts.

University-school cooperation. Cooperation between universities and schools can be very diverse. What they all have in common is that always both partners believe they benefit from cooperation. In the next two paragraphs we describe an example representing a ‘win-win’ situation for students, teachers and university students.

Since 2006, pre-service chemistry teacher students at Freie Universität Berlin plan and carry out project weeks for classes in years 7-13 concerning the topics “pollution” and “renewable energy,” within the frame of seminars. The aim of this cooperation between school and university is, on the one hand, to provide the students, within the framework of a project week, with an educational opportunity that enables them to intensively deal with topics from different subject-specific and social perspectives. On the other hand, the pre-service science teachers were provided with the opportunity to gather first practical teaching experiences within their undergraduate degrees because the courses were carried out by them. In consultation with the teachers of the school a central task for the pre-service science teachers was to put greater emphasis on integrating these social contexts into the planning and realisation of the project week on air pollution. Furthermore, the sequences were supposed to have an experimental focus, because the cooperating school was furnished with just one poorly equipped chemistry laboratory.

It seems this is something of a win-win situation for all parties. For example, for pre-service science teachers it helps in developing interdisciplinary and socially-relevant lessons. They gain teaching experiences in inquiry-based science learning with real students and get feedback from in-service science teachers. For grade-7 students they are learning in an authentic environment, working in a well-equipped university laboratory, interacting with young and engaged pre-service science teachers, and dealing intensively with one topic from different perspectives. For the in-service science teachers: observing pre-service science teachers, being relieved of some teaching duties, and learning something new because a week of interdisciplinary classes is like a form of professional development. The teachers have the position of an observer. They are not responsible for the lessons because the pre-service science teachers from the university conduct the lessons. Thus the teachers can observe their pupils and watch them from another perspective, they can learn about new methods, get ideas from the pre-service science teachers' work, talk about those ideas with them, and give them hints. In this way the teachers are reflecting lessons for one week, and this was then a kind of teacher professional development for most of the teachers who came with their classes.

Summer schools. Summer schools cannot replace lessons at school, but can act as a supplement. Yet, out-of-school/extra-curricular learning can be supportive in many aspects because students typically learn in smaller groups than at school, learn in a different learning environment (often at university) and the learning groups are more homogeneous in their interest compared to those in schools. Summer schools typically last for one or two weeks and are aimed at especially interested or talented students or students with special educational needs. Usually summer schools are offered at universities. Here, in most cases the students are provided with significantly better equipped laboratories than at school, are able to use different methods and learn about current scientific methods. Summer schools are designed to enable students to take part in a course that would enhance their scientific competences and skills, and also offers the students an insight into how chemistry is studied at university. Another aim is that the work carried out during the summer school will strengthen the participants' motivation to learn about chemistry and to choose a career in the sciences.

Certain topics are well suited for summer schools. Because summer schools typically take place during vacations. The sense of 'vacation' should be maintained. Thus, it is important that the contents of the summer school do not conform to the curriculum, but are put into a greater context. In order to attract students to universities during their summer vacation, the opportunity has to be interesting to the students. This can be achieved by choosing topics which are perceived relevant to them. Findings of the Curricular Delphi Study in Chemistry suggest that aspects of "interdisciplinarity," "health/nutrition," "current chemical research" and "nature of science," are particularly relevant for students (Bolte, 2008). Furthermore, it is important that a balance between theory and practice (e.g., practical work) as well as working on the topics and the tasks in a team is achieved.

How can school lessons benefit from summer schools? Teachers need professional development in relation to summer schools in order to give advice to the students about taking part. Teachers may also acquire ideas and suggestions for their own lessons if they sit in on lessons at summer school courses, attend lectures, and participate in final presentations. Students who take part in a summer school can report on it in class, give presentations about interesting aspects and show results or products of the summer school. Many summer school courses end with a final presentation. This allows participants to make a presentation about their experiments or prepare posters and to show presentations or experiments that they filmed. These films and presentations can then be used in subsequent school chemistry lessons.

An example of summer schools used in informal education occurs in the *Building-Blocks-of-Life* course run by the Department of Chemistry Education at Freie Universität Berlin (Streller & Bolte, 2007). The Department offers a summer school series called "Chemistry in a Class of Its Own" for students in upper secondary school (grades 11-13). In this five-day course the participants gain an insight into different professional scientific and technical areas. Each day of the five-day course starts with a special lecture given by university professors before the participants conduct experiments in the laboratory. Seminars also are held, giving an overview of and insights into topics that will be discussed in the lectures that day, and which focus on topics that the students consider relevant to their everyday lives. Additionally, the course helps illustrate how chemistry is studied at university. In the practical component of the course, students have the opportunity to experiment using laboratory equipment and chemicals which they do not usually find at school. Young people thus have an opportunity to deal intensively with current chemical issues and methods for one week during the summer holidays.

The course *Building-Blocks-of-Life* focuses on biochemistry. Everything we eat once lived or comes from a living organism, from animals or plants, and everything that lives is made up of the same basic biochemical building blocks. These are mainly carbohydrates, fats, proteins, and nucleic acids. This topic is a part of our everyday lives and should be relevant to students' lives. The priorities were set on working on the basics of biochemistry and on working with new media technology. The course supports students who are interested in chemistry and enjoy asking chemistry-related questions. It is designed to supplement chemistry lessons and courses in upper secondary school. In addition to the content, the joint visit to the university dining hall, during which experiences can be shared and acquaintances can be made, is an important part of the course concept as well. Finally, the presentations of the students' portfolios offer the participants the opportunity to share their knowledge with others. Professors, parents, and friends are invited to the final presentation.

Industry and school. In the neighbourhood of nearly every school one can find a company, a plant or even a huge industrial zone, but students and teachers do not know what happens behind the walls of companies. To enhance links between industry and school, and to use the industry as a place for out-of-school learning a project called ParIS (Partnership Industry and School) was initiated in Germany (see www.projekt-paris.uni-kiel.de/paris/). This dialog between industry and school can be a win-win situation for both. It helps to make lessons more practical and realistic, meaning that learning in science classes becomes authentic. The following benefits accrue:

- Students and teachers learn more about 'real' business, they get information first hand from experts,
- Insights into a company provide students with useful ideas into career choices, and
- Students gain awareness of professional routine and links between industry and society.

Cooperation between industry and school has advantages also for companies:

- Companies make contact with the people in their surroundings, meaning they can recruit young interested people for jobs, and
- Companies get feedback from students and teachers about their public relations activities.

In ParIS, the starting point of activity is utilising questions from the students. To find answers the students have to contact companies: Writing emails, looking at the company's websites, or making appointments to visit the company. Beside the cooperation between school and industry, an important goal of ParIS is to strengthen student self-directed learning. Students work in teams, use new media and present their results (Neumann, Gräber, & Tergan, 2005). A few examples might illustrate some scientific question from everyday life that can be addressed with the help from experts from industry:

- How can fruits turn into a jelly? – jam factory,
- Why can't curd cheese become sour? – dairy industry,
- How can textile dyes be produced? – dye industry, or
- How can one make a carpet? – carpet industry.

In ParIS students do not then learn science only from teachers and school books but also in real life situations. For many students this can become a way to see how important chemistry is to our life.

Another example is the Dead Sea in Israel, according to Hofstein and Kesner (2006) visits such as this are very rich in chemical ideas. The example is the story of *Bromine and its compounds*, based on the production of bromine and its related compounds (methyl-bromide, calcium bromide, potassium bromate, etc.) using brines as the raw material. The combination of Dead Sea's location, high air temperature, and the relatively high concentration of bromine ions influenced the development of a bromine industry, which is both unique and important for the Israeli situation. Hofstein and Kesner identify a number of products such as flame-retardants, pesticides, raw materials for the pharmaceutical industry, and many other important chemicals (about 60 in total). A case study like this not only affords chemistry learning, but benefits from an interdisciplinary approach. In this case this consisted of the underlying chemistry topics and concepts related to the industrial processes, the related technological, societal, economic, and environmental issues, and their interrelationships.

Relationship between chemistry and other school subjects

Chemistry has a nearly-reciprocal relationship with several other subjects in the formal educational curriculum. Concepts and skills from the other subjects are directly used and applied in chemistry and hence play a vital part in the learning of chemistry and the other subjects either directly use the concepts and skills of chemistry, or can provide a forum for the development and exercise of those concepts and skills.

Chemistry and the language of instruction. There are several potential general impediments that must be overcome or avoided when the language of instruction is used to teach and learn chemistry (see Chapter 5):

- Learning chemistry involves many new words (Coll, Ali, Bonato, & Rohinda, 2006), e.g., 6-8 words per lesson in science generally for 14-16 year olds (Merzyn, 1987).
- Many of these words were created specifically for use in chemistry (e.g., enthalpy, stoichiometry; Dahsah & Coll, 2007). Special attention has to be drawn to these when they are first used.
- Chemistry uses words from everyday life, but with an often subtly-different meaning (e.g., ‘bonding,’ ‘substance’). The different circumstances of chemistry when contrasted with those of everyday life must be pointed out if students are to avoid acquiring misconceptions.
- The meaning of logical connectives (e.g., ‘thus,’ ‘because,’ ‘however’) is vital in the conduct of explanation in chemistry, but may not be understood (Gardner, 1975). This potential problem should not be overlooked in the design of informal resources.
- Many common words, although having the same meaning in chemistry, may not be familiar to students (e.g., ‘abundant,’ ‘adjacent,’ ‘contrast,’ ‘incident,’ ‘composition;’ Cassels & Johnstone, 1985).
- Metaphors and analogies are widely used in chemical education (Duit, 1991). A metaphor is a generalised comparison that can be represented as ‘An X is a Y’ (e.g., ‘An atom is a planetary system’). These idealisations identify things that can then be compared in detail as an analogy (i.e., ‘An X is *like* a Y’ – ‘An atom is *like* a planetary system’) (the Bohr model). Hesse (1966) split a potential analogy into three parts: ‘positive’ relationships, which seem to be comparable; ‘negative’ relationships, which do not seem comparable; the ‘neutral’ analogue,

those parts about which a decision cannot be reached. An unfortunate choice of metaphor and/or an inaccurate valuation of its components can lead to misconceptions (Harrison & Coll, 2008). There are thus two issues here: careful choice of metaphors that are used, the source of them must be very familiar to the learners; and students must have an understanding of how metaphor and analogies work and experience in analysing and using them.

Chemistry and mathematics. Mathematical models are the most abstract forms of representation used in chemistry (Gilbert & Treagust, 2009a). A thorough understanding of and skill in the use of basic mathematical ideas, that is, in data manipulation, graphs, modelling, algebra, calculus, set theory, are vital for anyone studying chemistry at any advanced level. However, there is extensive evidence that many students are deficient in these respects (Orton & Roper, 2000).

There are several reasons that have led to this situation. First, syllabuses in chemistry (and the sciences in general) are not coordinated with those in mathematics for compulsory-age students. Second, the terminology used for mathematical ideas is often different in the sciences, and in the subject of mathematics. Students do not recognise ideas from mathematics when met in the context of science. Third, the level of mathematical demand in both the mathematical and science curricula for compulsory school-age students has been reduced in many countries in an attempt to increase the proportion of students who achieve certification in those subjects. Fourth, many mathematics teachers view their subject as a pure form of knowledge, and have no interest in its applications. Lastly, many science teachers do not themselves have a strong grasp of mathematical ideas and/or how to teach them.

Informal resources and their exploitation in non-formal contexts can address these issues. The bases of mathematical ideas have to be built up slowly, relating all the time to their use in the sciences, including chemistry. Little if any work of this type seems to have been done, beyond the splendid efforts of the various national 'Open Universities.'

Chemistry and other sciences. Given that chemistry provides explanations of phenomena at the submicroscopic level (see Chapters 2 and 4) for important areas of research such modern materials science (polymers, ceramics, food, medicine etc., see Gilbert & Treagust, 2009b; Meijer, Bulte, & Pilot, 2009), it is very surprising that little, if anything, seems to have been written about its contribution to other science subjects and hence to how chemistry-other subjects links can be maximised. It seems very probable that the problems faced are similar to those in relation to mathematical ideas (see above).

An understanding of 'material science,' in particular the theory and practice behind the development of innovations such as 'graphene,' depend on a grasp of chemical bonding in general. The major focus of biology at the moment is genetics, which depends on an exploitation of the hydrogen bonds that hold DNA together and hence which underpin gene manipulation. Although the subject of the earth sciences only currently forms a small part of chemistry (and other science) syllabuses, the growth of environmental education must surely lead to its increase (Orion & Ault, 2007).

These themes depend on specialist knowledge and the production of imaginative models through which to teach them. It seems likely that they will first appear as informal resources, and then rapidly be co-opted as non-formal resources.

Chemistry and technology. If chemistry seeks explanations of phenomena in the world-as-experienced, then chemical technologies can be seen as the design, use, and implications, of artefacts for human use that are based on chemical ideas. The relationships possible between the sciences and their associated technologies both as such and in educational curricula have been extensively discussed (e.g., Gardner, 1994). It is these applications of chemical ideas and their implications for personal, social, and economic life, that are of the greatest interest to students, but chemistry teacher education pays little attention to these matters. The most effective and efficient access to these issues does seem likely to come through the informal or non-formal route.

Table 3. Connecting formal learning with non-formal and informal learning

The role of the teacher as organiser of the learning process	The teacher provides orientation in the field/domain, focusing on relevant issues, providing interesting perspectives, meaningful activities, organising tasks, providing feedback, and assessing so that students see links between school and activities and experiences outside the classroom (e.g., museum visits), and come to realise they can learn science in other contexts/environments
Making tasks and assignments become more meaningful	Learning tasks should be more authentic, and not consist of small tasks – non-formal and informal learning environments typically provide authentic science experiences (e.g., work-integrated learning)
Providing opportunities for students to use digital information sources to foster learning	Facilitating connections and sharing between students about their learning experiences outside the classroom, by using social media
Recognition by teachers that some of their learners (but certainly not all) are far ahead in the use of digital/social media	Stimulating the learners to jump into challenging tasks at a general level

Redesigning formal teaching to connect with opportunities for non-formal and informal learning

This chapter closes with some hints of more thoroughly connecting the formal with the non-formal and informal sector. Table 3 gives some ideas how to connect the different domains and how to redesign non-formal/informal learning in a world with new (social) media?

THE PRACTICE OF CHEMISTRY TEACHING

Encouraging the engagement of potential learners

Encouraging the engagement of potential learners of chemistry-related themes raises the same issues as do the other sciences. The learner should be able to get access on any theme, it should be possible to learn about specific aspects of that theme, and that access to suitable sources should be available whenever wanted. The Internet looks like becoming the main vehicle for finding what is available and suitable. A major challenge for the school system and for general 'public service' adult education is to teach people how to do this. There are 'gateway' websites (British Council, 2009; Wikiversity, 2009), but no comprehensive database of popular books, newspaper articles, radio or TV programmes, seems to exist, although students can find such information provided they are set a challenging task or project (Ishak & Coll, 2009).

'Starting from where the learner is' implies that the knowledge-status of an individual must be diagnosed at the outset of the use of a particular educational resource. This will enable subsequent access to a resource to be tailored, to some extent at least, in the light of that information. All this can only happen if a diagnostic tool is included in the resource and if the user's response can be evaluated. The exhibits in science centres could all have this capability. The 'audience phone-in' capability of radio programmes can provide it, as can popular books, albeit the latter to a much lesser extent.

Using and providing access to suitable media is more straightforward. Visual learning is supported by museums and science centres and TV, also popular books and the Internet provided that the authors are alert to this possibility. Radio is axiomatically suited to auditory learning, whilst the recent introduction of 'talking books,' and the commentary accompanying 'blue-chip' TV programmes (Dingwall, 2006) are important sources. Science centres are obviously suited to learning through kinaesthetic experience, although it does seem possible that, having watched a TV programme or using the Internet, a learner could emulate the safest of any activities that had been shown at home.

What is written above makes no explicit mention of newspapers and magazines. It may well be these are best suited to alerting people to the existence and significance of particular items of new chemistry and chemical technology, rather than to an exposition of ideas – or to make the students aware about it if using these media in formal chemistry classes.

Addressing negative attitudes to chemistry

The meanings of three words are of importance here. The first is 'belief': this is the information that a person has about something (an object, situation, event, individual, group) (Jones & Martin, 2007). The second is 'attitude' which is a persistent inclination to respond in a consistent manner in the light of a strongly-held belief. The third is an 'inclination,' the likelihood of behaving in a certain way in the light of an attitude. So, when a strongly-held belief is triggered, the result is that the associated attitude is activated, such that the person will be inclined to behave in a specific way.

Many people have negative attitudes to chemistry and chemicals. These attitudes were developed: in response to repeated exposure to incomplete, inaccurate, or biased information; as a consequence of the formation of misconceptions despite exposure to accurate information; by reliance on the epistemologies of superstitions as the basis for determining what is true. However, what we are concerned with here is how to counteract these already-acquired negative attitudes, which can act as a block to a realistic understanding of chemical ideas.

The broad approach which provides an example of how we might go about changing beliefs is a wide variety of contexts is cognitive dissonance. This has been defined as: "*A psychologically unpleasant state which arises when an individual holds two beliefs that are in conflict with each other. This dissonance can be reduced by changing one of the beliefs*" (Festinger, 1957, p. 8).

This conflict is produced by causing a negative belief, in this case about chemistry, to be brought into active consideration whilst the basis for a contrasting positive belief is also being considered. The desired outcome is that the resulting dissonance is produced by the acceptance of the positive belief because it is more epistemologically convincing. This tension can be created and then relieved either by receipt of persuasive communication or, better still, by active participation in discussions. They both imply direct contact with a chemist or chemical technologist. The audio audience-feedback capability of radio and the email audience feedback of TV seem the media both best suited to the task and are widely accessible. Role-play can be used, a situation where a person has to pretend to hold the new belief and to argue on the basis of that (see Chapter 7). This might best be done on an ad hoc basis in a museum or science centre, provided that one could persuade suitable individuals to participate.

Much more work needs to be done on techniques of attitude change in general, not least in respect of chemistry and chemical ideas, particularly as issues of 'risk' and 'social implications' are of such high saliency in the public reaction to those fields.

The quality of learning of chemical ideas

The quality of learning sought and achieved will be governed by the type of explanation provided and by the width of its applicability, and by the students seeing the relevance and meaningfulness of this explanation for them. Five types of explanation are possible:

– An intentional explanation is the response to the question 'why, for what purpose, is this phenomenon being explained?'
– A descriptive explanation is a response to the question 'what are the properties of this phenomenon?'
– An interpretative explanation is a response to the question 'Of what is this phenomenon composed?'
– A causal explanation is a response to the question 'Why does the phenomenon behave as it does?' and
– A predictive explanation answers the question 'how will this phenomenon behave under other, specified, circumstances?' (Gilbert, Boulter, & Rutherford, 2000).

How might we enhance the quality of learning using informal and non-formal learning contexts? Well, whilst informal sources can presume learners' intentions behind the study of a phenomenon, this might well produce resources that are inflexible in terms of the other types of explanations that they provide. Resources that cover the whole range of purposes for study, in contrast, encourage 'progression,' that is, moving on from a concern with everyday life to take a broader view of chemistry. Those used in chemistry will have to be concise, yet suitably comprehensive in their treatment, and make full use of a range of representative forms, meeting the needs that are both implicit in the subject material and in the needs of learners. Popular books, TV, and the Internet, have great potential to meet these criteria in respect to chemical ideas, as with the other sciences.

Using modern chemical contexts

Pilot and Bulte (2006) suggest that a context that is suitable as a basis for learning (see Chapter 1) should:

– Focus the learner on the core concepts of chemistry. A group of contexts must be chosen that collectively addresses all the core concepts,
– Enable the learning of those concepts to be transferred to other contexts,
– Relate to an identifiable interest of the learner or a topic of public importance, and
– Meet the needs both of those who intend to go further in the study of chemistry and those who seek understanding of a particular use or issue.

Building on existing ideas, here those of Duranti (1992) and Gilbert (2006), suggests that a particular context is suitable if it:

– Is a situation that is contained by and within spatial, or temporal, or social, boundaries,

- Where distinctive events take place which can be focused on and thought about,
- With the use of suitable empirical activities by and discussion between learners,
- Involving the acquisition and use of specialist language as specific concepts are developed, and
- Which challenge or build on what is already known by the learners?

There seem to be no accounts of the actual competitive selection of contexts based on principles such as those. However, Bulte et al. (Bulte, Westbroek, van Rens, & Pilot, 2004; Bulte et al., 2005) have undertaken context-based curriculum development based on the notion of 'authentic practice' where the context selected is one in which the methodology adopted by the chemists and/or chemical technologists is clearly identifiable such that an analogy to it, suitable for work in a seminar room and laboratory, can be drawn.

These general and specific criteria seem equally applicable to the provision of both formal and informal chemical education. Text, diagrams, opportunities for practical work, and discussion, are all needed. This range of requirement suggests that a combination of source types would be appropriate, drawn from: the laboratories attached to science museums/centres, books, TV, the Internet. There must be examples in operation, case studies of them are needed. The issues in generating effective informal learning resources pose one set of challenges, as was outlined above. Having achieved that, the second challenge is now to make best use of them.

There are two ways that informal resources can be used: entirely separately from the formal education system or as an adjunct to or part of the formal education system, the 'non-formal' approach. 'Free-choice' education is a *sine qua non* for adult learning; its value for school-age children is being increasingly recognised (Falk, 2001). However, given that educational thinking is currently focused almost entirely on the formal sector, non-formal route is likely to be followed for some time to come.

Non-formal education

Informal resources are usually initially produced for free-choice use. However, because they are a response to contemporary issues and are attractively designed, they are very often co-opted for use within the framework of formal science education systems, as noted above. This is done in a number of ways:

- Introducing mobile informal resources into the classroom/laboratory (e.g., TV programmes, newspaper reports; Jarman & McClune, 2007),
- Bringing specialist guest speakers into the classroom (e.g., industrial researchers),
- Making structured use of visits to fixed informal resources (e.g., to a museum, zoo, aquarium),
- Making use of high-grade physical resources elsewhere (e.g., laboratories in science centres), and
- Using the pedagogy of the informal approach within the school curriculum (e.g., project-based work).

For this to happen, two conditions must be met. First, the existence and value of resources must be widely known. Second, the range, if not the amount, of such resources must increase.

Knowing what exists. No comprehensive catalogues specifically of informal resources exist for chemical education (although Internet search engines may have replaced traditional catalogues); they are subsumed within more general science education catalogues. In the UK, two such general catalogues are the British Council (2009) and Wikiversity (2009). They do not include evaluation data. The value of specific items of resource can be established against a number of questions:

– What range of provision is made within each mode of presentation?
– What is the uptake of that provision by the intended audience?
– What is the range of type and quality of the explanations that are provided?
– What is the treatment made of the nature of chemical inquiry?
– What is the treatment of the relationship between chemistry and chemical technology?
– How is the key issue of 'risk' addressed? and
– What evidence is there of the impact of the resource on the attitudes, knowledge, and skills, of the intended audience?

Developing new resources. There is no doubt that great science communicators through TV do exist; for example, in the UK Peter Atkins (chemistry), and Ben Goldacre (pharmacy) are distinguished book authors, albeit with very different styles. All such people have been described by Gladwell (2002) as being 'connectors,' that is "*individuals with a particular and rare set of social gifts – (that of) bringing the world together*" (p. 33), and as "*mavens*" (p. 66); people who accumulate knowledge and who can make their message effective by small adjustments to the personal, social, and environmental needs of their audience. There is surely a case for identifying all those who have and continue to contribute to informal chemical education and for seeking to systematically utilize their special skills.

One major obstacle to this broad ambition can be identified. Most effective chemical educators have, or have had, an association with a university. There is ample word-of-mouth evidence that these people are often discouraged by their managers from continuing with this line of work in favour of more orthodox chemistry research. This type of institutional attitude is waning under the influence of the competition for good quality, fee-paying, students (Burchill, Franklin, & Holden, 2009).

Work-integrated learning

In recent times there has been recent growth in programmes of study that seeks to enhance competency, and skill acquisition (Sovilla & Varty, 2011). Perhaps the most obvious example is work-integrated learning (usually referred to by the acronym WIL and also known by the term *cooperative education*). Such programs may be part of or outside formal learning environments. Even if located within formal learning programmes, they are often more flexible and student-directed in terms of their learning. It is important to distinguish here between work-integrated learning and workplace learning. According to Coll et al. (2009) and Coll and Zegwaard (2011), WIL requires integration of knowledge and skills from the educational institution to the workplace *and vice versa*.

WIL consists of programs that involve students doing a 'normal' academic programme of study, but which incorporates pre-determined periods of authentic work experience (Coll & Eames, 2006; Eames & Bell, 2005). There is now a considerable body of evidence that such programs prepare students well for professional life (Dressler & Keeling, 2011), and that such learning experiences help students, including chemistry students, develop a deeper understanding of the nature of their profession (Eames, 2001, 2002). The evidence also is that such programs provide students with skills desired by employers in the sciences and engineering sectors, and also in chemistry and related professions (Braunstein & Loken, 2004). Being situated in a real workplace, such experiences expose students to the real chemistry, chemistry that is interdisciplinary in nature. This helps them understand the culture of science and of chemistry as we now discuss, by considering how scientific and everyday thinking differ.

Science and scientific thinking is so different from everyday life, that it has been described as being a culture or subculture in and of itself (Aikenhead, 2001). According to Aikenhead, this is deeply problematic for many students, and it involves what he terms 'border crossing,' in which students are thought to cross-cultural 'borders' from their life world subculture into the subculture of science. This is similar to notions described by Bulte et al. (2005) who talk about the use of authentic science projects, with communities of practice of students using border crossing objects, with teachers acting as 'coaches' in this process. This transition or border crossing is difficult for any student even when school science beliefs are aligned with their beliefs, and they come from a Western cultural background – the dominant cultural regime of scientific endeavour (Cobern, 1998; Cobern & Aikenhead 1998). WIL is reported to aid this border-crossing or enculturation for all students, regardless of their background (Eames & Bell, 2005; Eraut, 2004). This is interesting, considering that for students from non-Western cultures such as indigenous peoples, such a transition is reported to be highly problematic (Glasson, Mhango, Phiri, & Lainer, 2010). If the culture of science is seen to be very different from the culture of the learner, (as it is suggested is the case for indigenous persons, see Glasson et al., 2010; Paku et al., 2003), then this results in assimilation where Western science is 'inflicted' on indigenous students, and all other beliefs of science must be abandoned in the process. As noted above, there is now evidence in the literature that WIL programmes help indigenous and non-indigenous students become enculturated into science and scientific thinking (Eames & Bell, 2005), and develop a deeper understanding of the nature of science (Glasson et al., 2010; Paku et al., 2003).

How does this occur? It appears that cooperative education or WIL allows students to develop an understanding of the nature of science during practice, and if this is done in a positive way, such learning may exert a positive influence on their attitude toward science. It seems unlikely students will develop positive feelings about science and scientists if they feel alienated from this subculture. If one accepts that to understand science one needs to actually do some science, then programs of study that allow students to do science, and work alongside professional scientists have considerable scope to enhance student understanding of the nature of science, and this may smooth their enculturation into the subculture of science (Eames & Bell 2005). Moreover, WIL allows students to be involved in decision making, problem solving and being able to make informed choices about the science they are doing, and potential careers in science. This not only gives the student experience within the science subculture, but it gives them an understanding of what it means to be a scientist within a particular discipline; viz., to begin the enculturation process.

Work-integrated learning programs, of the type described above, are common in chemistry (Eames & Bell, 2005). However, they mostly confined to higher education, with few reports of chemistry WIL programmes available in compulsory schooling. Some reports of school-level WIL programmes upon closer examination suggest they are something of a pale imitation of idealised WIL (Johnston, 2011); that is, they seldom involve structure or planned learning outcomes. However, of interest are reports that WIL does allow students to interact with their epistemological assumptions (Chin, Munby, Hutchinson, Taylor, & Clark, 2004). What this means is that science or chemistry students, even at school, can begin to address the process of border crossing, which is reported to be facilitated by WIL programs in higher education, in the way described above. One area of WIL that is fairly widespread at the school level is vocational education (Donnelly, 2009). Such programmes, as the name suggests, are heavily focussed on students gaining skills or insights into specific career options (e.g., on 'work shadowing' programmes). Donnelly (2009) argues that such programmes "*offer scope for a humanised version of science, conferring autonomy on the student*" (p. 244), consistent with the notions of informal and free choice learning described above. Thus autonomy in learning is a common feature of even highly structured WIL programmes, since the learning is 'messy,' often unplanned, and any learning comes from reflection on vicarious experiences (Coll et al., 2009). Mullis et al. (2008) observe that a large part of science teaching is undertaken in vocational or pre-vocational contexts, indicating that WIL programmes at school, whilst highly vocationally-focused are an important part of the curriculum, something supported by the European Commission (see European Commission, 2004).

SUMMARY: KEY SENTENCES

– There is a growing interest in learning that occurs in informal and non-formal environments.

– There is evidence that learning does occur in informal and non-formal settings but also a paucity of research about how learning occurs, how it might be facilitated, and how it might (or should) be integrated into formal schooling.
– It is open to debate if we should even seek to integrate informal/non-formal and formal education, but the immediacy of such environments could provide potent opportunities for the learning of science.
– There is a need for much more research and development projects related to informal and non-formal chemistry education that might change the vision and focus of curriculum.
– We need to know more about what professional development would facilitate learning in informal and non-formal settings.

ASK YOURSELF

1. Explain the difference between formal, informal, and non-formal education.
2. Identify some aspects of chemical knowledge that you learned in an informal context?
   - What are the strengths and weaknesses of non-formal chemical education?
   - What piece of education research could most change teachers' perceptions of the value of non-formal chemical education?
3. What, specifically, should be added to the pre-service teacher education in respect of non-formal chemical education?

HINTS FOR FURTHER READING

Stocklmayer, S., Rennie, L., & Gilbert, J. K. (2010). The roles of the formal and informal sectors in the provision of effective science education. *Studies in Science Education*, *46*, 1-44. This paper summarises the causes for concern about formal science education and the major approaches being taken to address them are outlined. The contributions that the informal sector currently makes to science education are discussed.

Fraser, B. J., Tobin, K. H., & McRobbie, C. J. (2012). *Second international handbook on science education* (Part VIII Out-of-school learning, chapters 70-78). Dordrecht: Springer. The chapters provide a review of research on multiple facets of out-of-school science learning, e.g. lifelong learning, in connection to museums or by TV.

Stocklmayer, S., & Gilbert, J. K. (2011).The launch of IJSE (B): Science communication and public engagement. *International Journal of Science Education Part B*, *1*(1), 1-4. The launch of the science communication Part of IJSE is detailed, explaining the rationale and aims of the newly launched periodical.

Coll, R. K., & Zegwaard. (eds.). (2011). *International handbook for cooperative and work-integrated education*: *International perspectives of theory, research and practice* (2nd ed.). Lowell: World Association for Cooperative Education. This handbook provides a comprehensive picture of work integrated education in its numerous guises and settings. It shows how theory and research have influenced the practice of work integrated learning.

RESOURCES FROM THE INTERNET

British Council: *www.britishcouncil.org/talkingscience-media.htm*. This website offers access to a lot of science related informal resources, e.g. film, TV, podcasts, or video.

Top 10 Amazing chemical reactions: *listverse.com/2008/03/04/top-10-amazing-chemical-reactions/*. This website provides excellent quality videos of exciting, often hazardous, chemical reactions.

Career Services. (2006). *12 Essentials for success*. East Lansing: Michigan State University: *careernetwork.msu.edu/pdf/Competencies.pdf*. This article summarises major research in the US about graduate transition into the workforce, arguing that modern graduates need an ever-increasing skill set, and that work-integrated learning is now an expected component of any résumé.

East Lansing: Collegiate Employment Research Institute, Michigan State University: *www.ceri.msu.edu/young-professionals/*. Chao, G., & Gardner, P. D. (2008). *Young adults at work*: *What they want*, *what they get and how to keep them.* The article considers differences in expectations between near-retirees or 'baby boomers' and new graduates entering the workforce. It argues that enculturation into the workforce via work-integrated learning can help ease graduate transition into work.

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RACHEL MAMLOK-NAAMAN, FRANZ RAUCH, SILVIJA MARKIC
& CARMEN FERNANDEZ

10. HOW TO KEEP MYSELF BEING A PROFESSIONAL CHEMISTRY TEACHER

Effective professional development needs to provide an opportunity for teacher reflection and learning about how new practices can be evolved or shaped from existing classroom practice. This is not a simple task in that it requires teachers to re-examine what they do and how they might do it differently. In addition, the attainment of complex learning goals in science by students demands significant change in teachers' roles. Based on research findings, teachers who attend continuous development professional development (CPD) workshops, are more satisfied with their teaching, and have a closer contact with academic and education institutions on a professional basis. In addition, they get a sustained and continuous support, they feel a sense of ownership regarding their involvement in the education system, and become more concerned about improving their practice and learn how to share their ideas and experiences with their colleagues. This chapter discusses various strategies of professional development.

THEORETICAL BASIS

The outstanding teacher is not simply a 'teacher,' but rather a 'history teacher,' a 'chemistry teacher,' or an 'English teacher.' While in some sense there are generic teaching skills, many of the pedagogical skills of the outstanding teacher are content-specific. Beginning teachers need to learn not just 'how to teach,' but rather 'how to teach electricity,' 'how to teach world history,' or 'how to teach fractions.'
(Arthur N. Geddis, 1993, p. 675).

Teachers' knowledge and the need for life-long teachers' professional learning

One of the goals of the chemistry-teaching community is to develop more effective and scientifically aligned strategies to teach chemistry. For example, teachers need to have a clear and comprehensive view of the nature of a scientific model in general, how their students construct their own mental models, how the expressed models can be constructively used in class, how to introduce scientific consensus models in their classes, and how to develop good teaching models, and how to conduct modelling activities effectively in their classes. Furthermore, teachers need

I. Eilks and A. Hofstein (eds.), Teaching Chemistry – A Studybook, 269–298.

to understand how such models relate to macroscopic and submicroscopic features of substances as well as how the two relate to each other (see Chapter 4).

Regarding modelling, Justi and Gilbert (2002) suggested that, most teachers do not emphasise either the need for considering the scope and limitations of models during the process of modelling, or the importance of discussing with the students such matters when presenting a model. Justi and Gilbert suggest that there is a gap between students and their teachers concerning students' understanding, as well as in relating the task that they have to deal with. For the teacher the task is a routine exercise, but for the students it is a novel problem. The difference between an exercise and a problem is the result of differences in the level of familiarity with similar tasks that the individual brings to it (Bodner & Domin, 2000).

Erduran (2003) proposed that a lack of effective communication between students and teachers can lead to a mismatch between what is taught and what is learned. In the context of science lessons, symmetry between the nature of teachers' understanding of a particular science topic and students' ideas regarding this topic is critical, because such a match illustrates what scientific knowledge is being taught and learned in the classroom. This is, in our example, inclusive of the central aspect of the macroscopic/submicroscopic relationships as well as the role of modelling involved in establishing these relationships.

Accomplished teaching of science can be defined in terms of the knowledge which teachers use in their teaching (Guskey & Huberman, 1995; Magnusson, Krajcik, & Borko, 1999; Shulman, 1987). This knowledge has been categorised as subject matter knowledge (SMK), general pedagogical knowledge (PK), and pedagogical content knowledge (PCK) (Borko & Putnam, 1996). Within this categorisation, PCK is concerned with the teaching and learning of a particular domain: knowing how students learn within that domain, knowing their common misconceptions and the particular difficulties and challenges of that domain, and being able to apply this knowledge to teaching and learning within that particular domain (Shulman, 1987). Another aspect of accomplished teaching termed 'scholarship of teaching' is proposed by Hutchings and Shulman (1999). They suggest that in addition to effective teaching, teachers should be able to articulate their teaching actions and thinking in such a way that others can learn from it and should be available for community discourse and study. They also claim that this public feature of teaching improved teachers' learning and performance through reflection and professional discourse. According to Hofstein, Shore, and Kipnis (2004), accomplished teachers who are involved in an inquiry-type program for example, should have the following skills and abilities:

- To encourage students to interact professionally, including sharing knowledge with their peers, community members, or experts,
- To help students: solve problems, ask high-level questions, and hypothesise regarding certain unsolved experimental problems,
- To assess students using a variety of alternative assessment methods,
- To customise the new activities according to their needs, and make decisions regarding the level of inquiry suitable for their students, and
- To align the experiment with the concept taught in the chemistry classroom.

It is suggested that good teachers are easy to recognise in real life. Since we were students we have been observing what good teachers do and we are able to perceive when a teacher have the things in classroom under control, when we really learn in response of a good teacher management and when this is not the case. Factors that identify "best teaching" can be recognised by every person who has been in the school context either as a pupil, parent or teacher. General factors such as "knowing the subject and to like children" might be recognised by all conceivable persons (Kind, 2009). We can also recognise that different good teachers can do things in different ways and still we would say they are good. Part of these differences are related to the subject matter this particular teacher teaches, that means there is something very special in being a good chemistry teacher that is different from be a good language teacher, for instance. With these claims in mind, we can consider teaching as a professional activity that is based on a group of actions intentionally anticipated by a teacher in order to promote conceptual, procedural and attitudinal learning in school. This chapter helps to understand where this knowledge of the teachers stems for. Anyhow, it is also clear that every chemistry teacher has potential of getting a better teacher by getting more experienced, reflecting his professional work, and continue life-long learning about new research evidence and newly developed practices in the domain of chemistry education. This chapter will also give a justification why every teacher needs continuously further learning and we will discuss how to organize this way in the best possible manner.

The different foci of chemistry teachers' professional knowledge base

During a chemistry lesson a lot of different things happen and at the same time. Organizing, controlling and assessing the learning process of the students, dealing with students' feedback and difficulties, or providing information and methodological support are in the root of good teaching. And even though there are some general principles in being a good teacher in any subject, there are several peculiarities relating to the specific content, in our case chemistry. This is the central idea in the *pedagogical content knowledge* (PCK). PCK was, for the first time, described by Shulman in 1986 although in several countries related concepts existed for much longer time. One example is the German concept of *Fachdidaktik* (Fensham, 2004). However, PCK is used to distinct a specific knowledge, specifically focusing on the teaching of chemistry from subject matter knowledge or content knowledge (SMK/CK), e.g. in chemistry, and general pedagogical knowledge (PK). The relationship between PCK, PK, and SMK is presented in Figure 1.

Shulman described PCK as "*that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding*" (Shulman, 1987, p. 15). Shulman's definition was later expanded upon and more precisely described by different scholars. For example, Van Driel, Verloop, and De Vos (1998) considered PCK to be a specific form of craft knowledge, or Loughran, Milroy, Berry, and Gunstone (2001) defined PCK as:

"*the knowledge that a teacher uses to provide teaching situations that help learners make sense of particular science content.*"

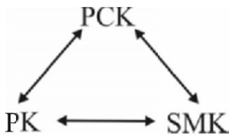

Figure 1. The relationship between PCK, PK, and SMK/CK

Shulman (1987) claimed that teachers need to possess or develop strong PCK to be the best possible teachers they can be in their specific subject. Loughran et al. (2001) described this need as that which teachers must know in order to best teach content to students. PCK became increasingly accepted as a heuristic device for understanding this specific domain of teachers' knowledge and beliefs relating them to their classroom practices in their subject (Gess-Newsome & Lederman, 1999).

By definition, PCK is subject- and domain-specific (Shulman, 1986, 1987). The idea is that there cannot be one common strategy that can be operated on each different content in the teaching of language, science or history. The teacher needs to select and adapt teaching approaches and methods for each specific situation, in their subject and with respect to the learners and to the individual content. Geddis (1993) described the situation as:

> The outstanding teacher is not simply a 'teacher,' but rather a 'history teacher,' a 'chemistry teacher,' or an 'English teacher.' While in some sense there are generic teaching skills, many of the pedagogical skills of the outstanding teacher are content-specific. Beginning teachers need to learn not just 'how to teach,' but rather 'how to teach electricity,' 'how to teach world history,' or 'how to teach fractions.' (p. 675)

In addition Bucat (2004) added to the sentences from Geddis: "... *how to teach 'stoichiometry,' or 'how to teach chemical equilibrium,' or 'how to teach stereochemistry'*" (p. 217).

A common view of PCK is that it is bound up, and recognisable, in a teacher's approach to teaching particular content (Loughran et al., 2001). To create such an approach, a transformation of the SMK is necessary (Geddis, 1993; Van Driel et al., 1998). Revisiting the above selected example on scientific models can provide good illustration. On the case of scientific models, Taber (2008) for example, discussed the teacher's role in such and similar transformational processes. Whereas the curriculum developer adopts a scientific or historical model into a curriculum model, the teacher is forced to make a second adoption of the curriculum model into a teaching model. The latter step is done on the basis of his PCK. His PCK offers the teacher a framework for selecting the pedagogy to explain the curriculum model to his individual learners. Nevertheless, Taber also clearly stated that this is not necessarily the same as what students finally will have learned. But, without well developed PCK, adopting scientific or curricular models to specific teaching and learning conditions will be doomed to cause probably many more problems and mistakes in the students' learning. And without sufficiently developed PCK the teacher might not even be able to recognise and understand the students' problems.

From this example we can initially think about what the dimensions of PCK are. The teacher needs knowledge about common learning difficulties and alternative conceptions of students. But he also needs knowledge about experiments, physical models, media and available materials that might be used. With Van Driel et al. (1998) PCK in general consists of three dimensions:

– Knowledge of students' conceptions with respect to a domain or topic and understanding specific student difficulties in that area,
– Knowledge of representations of subject matter for teaching, and
– Knowledge of instructional strategies incorporating such representation.

More specifically, Magnusson, Krajcik, and Borko (1999) conceptualised PCK consists of five components. In the case of chemistry:

– Orientations toward chemistry teaching,
– Knowledge and beliefs about the chemistry curriculum,
– Knowledge and beliefs about students' understanding of specific chemistry topics,
– Knowledge and beliefs about assessment in chemistry, and
– Knowledge and beliefs about instructional strategies for teaching chemistry.

PCK is composed of different sources. Grossman (1990) identified four sources from which PCK is generated and developed in the sense described above, and Appleton and Kindt (1999) added a fifth one:

– Observation of classes, both as a student and as a student teacher, often leading to tacit and conservative PCK,
– Disciplinary education, which may lead to personal preferences for specific purposes or topics,
– Specific courses during teacher education, of which the impact is normally unknown,
– Classroom teaching experience, and
– Recommendations from trusted colleagues.

This means that PCK is a very personal domain of knowledge. It is developed step-by-step, constantly refined on the basis of individual experiences and largely influenced by beliefs. These beliefs include epistemological beliefs, general educational beliefs, content-related beliefs, beliefs about curriculum orientation and much more. Hermans, Van Braak, and Van Keer (2008) stated that beliefs are the permeable and dynamic structures which act as filters, through which new knowledge and experiences are screened for meaning (Pajares, 1992). This makes it very difficult to grab onto PCK because it is intangible and rarely made explicit by teachers. It only comes to the fore when teachers act or start to explain what they are doing in class. Consequently, dialogues between teachers and their colleagues while sharing experiences or negotiating joint teaching strategies might represent an excellent source for examining, reflecting and revising PCK, e.g. in courses combining theory of learning with experiences and reflection (Kind, 2009).

Understanding professional development

We assume that experienced teachers become better over time at teaching school chemistry. Good teachers have as part of their PCK a good repertoire of instructional strategies related to a specific topic and know about the difficulties students might have related to that topic. So they have an extended repertoire about how to deal with these difficulties in the classroom and transform the difficulties in learning opportunities for those particular students. But, this knowledge is developed over time and the result of initial training, experiences, and information from external sources. On the other hand one can observe that the teachers sometimes lose chemical knowledge. New knowledge is learned on the one side and become better organised while other knowledge is forgotten (Kind, 2009). The teachers unconsciously select the knowledge to be kept by its importance for the process of teaching. So in the life of a teacher knowledge continuously changes and is re-organised. This change contributes to different steps of a teachers' professional development. For this process, Berliner (1988) proposed a five stage model of teacher development, as follows:

- *Novice* (classroom teaching is rational and relatively inflexible),
- *Advanced beginner* (the teacher develops strategic knowledge and classroom experiences and the contexts of problems begin to guide the teacher's behaviour),
- *Competent* (the teacher makes conscious choices about actions, knows the nature of timing and what is and is not important),
- *Proficient* (intuition and know-how begin to guide performance and a holistic recognition among contexts is acquired; the teacher can predict events), and, finally
- *Expert* (intuitive grasp of situations, teaching performance is fluid as the teacher no longer consciously chooses the focuses of attention).

But, what are the important domains making the teacher more proficient and in the end an expert? One model describing how the teacher professional change can be understood but also how activities in teachers' in-service training can be reflected is the *Interconnected Model of Teachers' Professional Growth* (IMTPG) by Clarke and Hollingsworth (2002). The IMTPG model reminds us that in professional development the teacher is a learner. Thus, we have to consider the basic theories of learning and the role of influencing factors on a successful and sustainable learning process also for teachers' professional learning. From Clarke and Hollingsworth, any teacher training should consist of a process based on self-reflection and action, which takes into account the:

- Personal domain (beliefs, attitudes, and pre-experience),
- Practical domain (authentic teaching practices of the teacher),
- External domain (topic requirements, media and curriculum), and
- Domain of consequences (goals and effects).

The IMTPG model suggests that a change in one of the domains is translated into another domain through the mediating processes of enactment and reflection. From the IMTPG one can easily derive that teachers' (ongoing) professional development should not be solely based on a persistent, structural process of top-down in-service training. Effective professional development needs to be connected to explicating the teachers beliefs, attitudes, and experiences, to allow them making own experiences, and finally to experiences and learn about the effects.

From theory to practice

As stated above, teacher education needs a good blend of theoretical input, adopting it on the base of attitudes beliefs and prior knowledge, as well as collecting and reflecting experiences. Traditionally, the relationship of theory and practice in teacher education was referred to as the paradigm of *technical rationality.* The basic claims of this paradigm are (Schön, 1983):

– There are general solutions (academic theories, administrative rules etc.) to practical problems,
– These solutions can be found outside practical situations (e.g. in academic institutions, technical laboratories or administrative centres),
– The solutions can be transmitted to practitioners through courses, publications, prescriptions etc.). If correctly applied to practical situations they will solve the practical problems.

Based on this paradigm, it was expected that professional development was accomplished by the transmission of tested theory and that innovations in educational practice are produced by academic research results, by administrative regulations and by corresponding control mechanisms to make sure that the findings are applied as specified. This concept implies a separation of theory (knowledge production) and practice (knowledge utilisation), and a separation between professional and customer.

One effect of the idea of technical rationality in education was the application of mainly top-down approaches in teacher training. In the past, teachers were not involved intensively in the development of curriculum materials. Most of the development processes were mainly "top-down" conducted by academic centres. In recent years, teachers are involved in the development of materials (e.g., Salters Chemistry; see Chapter 1). This issue increases teaching ownership, and is called "bottom-up." Another effect was a genuine mistrust of the practitioner implementation of the innovations. Within the conceptual framework of technical rationality the teacher is working on a low level of generality and is merely applying what has been predefined in the academic and administrative power-structure above the teacher. Improvements of school practice are, in this view, primarily results of improved general and applied theories and norms transmitted to the practitioner (and of incentives and control mechanisms to ensure their correct application). The teacher receives the necessary technical knowledge but has no part in contributing to it.

The dominant character of this traditional paradigm of educational innovation and teacher professional development is changing. The paradigm of technical rationality proved to be inefficient to cope with the complexity of educational practices and with social change. It became clear that its validity depends on the existence of clear and unambiguous aims and on the predictability of practical situations and effective strategies to cope with them.

Instead of technical rationality modern concepts of teacher learning use the paradigm of *reflective rationality* (Altrichter, Feldman, Posch, & Somekh, 2008) as:

– Complex practical situations ask for context-specific solutions because they are characterised by ambiguous and partially contradictory aims (e.g. they involve problem definitions before problem solutions can be found),
– The problem definitions and the strategies necessary to cope with practical situations have to be produced within practical situations by teachers individually or in co-operation with each other, and
– The situational understanding gained by joint reflection on action cannot be applied to other situations, but can be made accessible to other practitioners to be tested in their own practice and further developed by them.

The paradigm of reflective rationality has considerable implications for understanding and organising teachers' professional development. Professional knowledge is defined by the ability to generate context-specific local knowledge in order to further develop the quality of services. Complex practical situations are managed through co-operation with other professionals and also by allowing students to play important roles in this process in which they are neither clients nor customers but 'co-producers.' This concept of professional knowledge involves a new balance between action and reflection and between individual autonomy and co-operation. With Stenhouse (1985),

> the outstanding characteristics of the extended professional is a capacity for autonomous professional self-development through systematic self-study, through the study of the work of other teachers and through the testing of ideas by classroom research procedures. (p. 144)

Understanding of both rationalities is important. To accept the tension between them and to cope with them is one of the difficult challenges in teachers' professional development. Therefore, that the goals and approach of the programs for teachers' professional development should include:

– Helping teachers become aware of the need to stimulate and support students in learning activities in the domain,
– Exposing teachers to central ideas in the domain and a variety of instructional activities,
– Encouraging teachers to customise activities in the domain to their needs and implement them effectively,
– Providing guidance to a wide range of teachers enabling them to evidence their practice and improve their knowledge and skills,
– Guiding teachers in collecting evidence of accomplished teaching,

- Facilitating meetings where teachers could discuss and reflect on the documented practice, presenting artefacts as evidence that demonstrated their changing practice, and
- Helping teachers select documented evidence to illustrate their development in their personal portfolio.

Also, Huberman (1993) stated that persistent and long-term interaction with people from outside the specific school setting is unavoidable for achieving research-based innovation of teaching practices and professional development. The process must be centred on collective reflections of both the teachers and their research partners with respect to current and altered teaching practices (Haney, Czerniak, & Lumpe, 1996; Beijaard & Verloop, 1996; Riquarts & Hansen, 1998).

For keeping oneself learning while being a teacher the framework of professional practice might be the most important. As Abell (2007) stressed that the situated learning perspective (see Chapter 1) could also be well applied to teacher learning. That means that practicing teachers' learning does take place in direct relationship to their professional environment. In this case, the role of every teacher is both being a learner as well as being a partner for other teachers for their professional development. That means that every teacher also has responsibility with novice colleagues in terms of helping them to reach the expertise you already have and at the same time improve your own. This is possible working as a mentor of a novice teacher.

A good metaphor about for the joint learning of teachers is the guided tour (Nilsson, 2008):

> It might well be argued that in order to benefit the most from a guided tour requires the guide to be able to make explicit his/her knowledge about the different places. Hence, one important aspect for the guide must then be to help the visitor to see and recognize aspects within the area that he/she would not have been able to see alone. Thus, the guide could provide the visitor with information about what to see, how to act, communicate and respond to people as well as places with which they interact during the tour. However the guide must not only be able to know about the area, but also be able to conceptualize this knowledge and tell interesting stories about it. It could well be argued that another important aspect of the guiding metaphor...might then be that when preparing for and then later guiding the visitor, the guide will see and recognize aspects within the area that he/she might not have noticed before. (p. 100)

However, not every piece of information will be available within one's own school environment. Teachers need to familiarise themselves continuously also with new evidence from educational research and with ideas and methods for better practice from the whole community of chemistry education. The teachers need to understand and reflect upon the implications for themselves as teachers and for their learners in the classroom before they adopt and adapt them. This could be better done jointly with colleagues as a collaborative learning process. If new evidence or teaching approaches differ greatly from the teachers' previous practice, joint reflections can help in reshaping the teachers' beliefs regarding the practice of chemistry teaching and learning. It thus involves careful consideration of core principles and issues as well as contextualising them in the process of developing practice. For such a process to occur teachers need input from outside their own school and support for the most promising professional development.

As stated before, traditional methods of conducting externally supported professional development have usually been top-down, short and occasional (Loucks-Horsley, Hewson, Love, & Stiles, 1998). Such approaches have been shown to have limited effects. Our discussion shows the need for different strategies, with bottom-up, long-term and structured approaches. Research on CPD highlights some general features that characterise effective CPD programs (e.g., Ball & Cohen, 1999; Bell & Gilbert, 1994; Kennedy, 2002; Loucks-Horsley, Hewson, Love, & Stiles, 1998; Marx, Freeman, Krajcik, & Blumenfeld, 1998; Putnam & Borko, 2000; Taitelbaum, Mamlok-Naaman, Carmeli, & Hofstein, 2008):

– Engaging teachers in collaborative long-term inquiries into teaching practice and student learning,
– Situating these inquiries into problem-based contexts that place content as central and integrated with pedagogical issues,
– Enabling teachers to see such issues as being embedded in real classroom contexts through reflections and discussions of each others' teaching and/or examination of students' work, and
– Focusing on the specific content or curriculum teachers will be implementing such that teachers are given time to work out what and how they need to adapt what they already do.

Based on Lipowsky (210) and the literature cited above we can claim that effective CPD programs for teachers:

– Are long-term in nature and enable a more in-depth discussion of contents because short-term professional development initiatives seem to be largely unable to impact routines,
– Are characterised by a variety of methodological settings (alternation of input and work phases, experimentation, training, and reflection sequences),
– Clearly tie in with the participant's classroom practice (e.g. start out from concrete challenges),
– Place a subject-didactic focus on selected issues and allow to address contents in-depth,
– Encourage a critical questioning of fundamental convictions of teachers and such form the basis for a lasting change of attitudes and classroom practice (including a systematic reflection of one's own practice and of the underlying assumptions),
– Explicitly provide for cooperation among teachers beyond the event (e.g. promoting and using regional networks),
– Involve several teachers of a given school and encourage the in-school dissemination of the course contents, and
– Offer external support for the in-school implementation of the contents.

In summary, effective professional development needs to provide an opportunity for teacher reflection and learning about how new practices can be evolved or shaped from existing classroom practice. This is not a simple task, in that it requires teachers to re-examine what they do and how they might do it differently. In addition, the attainment of complex learning goals in science by students demands significant change in teachers' roles and classroom practice. The practice section of this chapter will give insight in promising strategies to keep prepared for it.

THE PRACTICE OF CHEMISTRY TEACHING

For effective teachers' continuous professional development (CPD), teachers need sustainable interaction with external partners (Huberman, 1993). Teachers need guidance and support throughout the various stages of implementation of innovations in the classroom (Loucks-Horsley & Matsumoto, 1999). The guidance and support may be given by authors of textbooks and journals, regional consultants from education departments, chemistry educators from university, national or regional centres for science teacher training, or through in-service CPD programs. The programs for in-service chemistry teacher training range from individual learning, via short workshops, to long term interaction. The programmes vary widely with respect to the philosophy, content, and format of the learning experiences. In general, we can see a range from conventional top-down approaches of knowledge dissemination, interactive modes of training, to bottom-up strategies where the teachers become the inventors and promoters of change.

From research we know that the traditional methods of top-down, short and occasional trainings were shown to have limited effects (Loucks-Horsley et al., 1998). However, in some cases such approaches are the only offers available for the teachers. For interactive and long-term courses, we know that teachers attending systematic CPD programmes (despite the fact that they are time consuming), are more satisfied with their teaching, and have closer contact with academic and educational institutions on a professional basis. They get sustained and continuous support; they feel a sense of ownership regarding their involvement in the education system, and become more concerned about improving their practice and learn how to share their ideas and experiences with their colleagues (Loucks-Horsley & Matsumoto, 1999).

All models have the potential to contribute to chemistry teachers' CPD. Utilising different examples, we will highlight the different possibilities, strength and weaknesses.

Traditional approaches to teachers' continuous professional development

Traditional approaches of teachers' in-service professional development are to be characterised by the following characteristics:

– Information transfer is one-directional, from an educator, trainer, or author towards the teacher,
– Training is based on single isolated contacts, e.g. in one- or half-day events, by single books, journal articles, or by receiving newly published teaching materials, and
– Innovation is not focused by an analysis of the individual teachers' needs and experiences.

Although educational research is very critical on such top-down approaches, also these programmes offer opportunities for a teacher to get new ideas for teaching.

Books, chemistry and science teacher journals, and the Internet. Books and journals are a good resource for information. Educational publishers offer a lot of different types of publications. Also the Internet provides a lot of information, from free access online journals, via materials from science teachers' organisations or chemical industry, towards tested materials from other chemistry teachers all over the world. Professional teachers should analyse newly published textbooks in order to examine whether they suggest innovative and promising strategies. Also science teachers' journals (e.g. the *Journal of Chemical Education* published in the US or *School Science Review* from the UK) should be read regularly. The journals offer the teachers actual overviews about new pedagogies, teaching ideas, innovations in educational technology, or experiments with specific focus on chemistry education. Most countries have their own chemistry or science teachers' journal, discussing innovation with specific focus on the national or regional circumstances. Reading the books and journals will mainly affect the cognitive domain. One knows more about potential content and strategies. However, just reading a book or journal will not lead to any change. The teacher needs to adopt the written information towards the specific circumstances. The teachers need to find their own ways, and need time and patience in order to get the described innovations to work. Nevertheless, if there are no other alternatives, books and journals for chemistry and science teachers might offer opportunity for improve the teachers' SMK, PK and PCK.

Chemistry and science teacher congresses. In nearly every country special conferences for science teachers are available. Mostly the congresses are organised by national science teachers associations (e.g. the *Association for Science Education* in UK), by the educational divisions of the national chemical societies (e.g. in Germany by the division of chemistry teaching of the German chemical society), or by universities or teacher training centres (e.g. the *Woudschoten Chemie Conference* in the Netherlands organised by the University of Utrecht). Through presentations, workshops and exhibitions the teachers are provided with a lot of information about new developments in the subject matter of chemistry, e.g.

nano technology. But presentations and workshops also deal with new curricula, pedagogies, educational technology, or teaching materials. Also here the potential for sustainable change is limited. The contact time is short, the learning is not connected to experience, and after having been at a congress limited time and opportunity may hinder adoption and application. However, visiting the chemistry teacher conferences does offer an opportunity for getting a sense of innovation, collection of materials, and may initiate contact to external partners and colleagues from other schools.

Chemistry teacher professional development courses. In many countries, national science teacher associations, universities, or national and regional centres for science and chemistry teacher training offer short-term sometimes isolated training events for chemistry teachers. For example, in Germany, the German chemical society established seven regional chemistry teacher training centres offering a large number of courses from half- to three day duration. Such events are in most cases half- or one-day events. Presentations and workshops offer information on actual developments in chemistry or in the pedagogy of chemistry teaching. Sometimes these courses include the possibility to try out new classroom experiments or teaching materials. The more promising course offers are characterised by approaches which combine learning of SMK, PK and PCK. For example, in the Israel National Center for Chemistry Teachers at the Weizmann Institute of Science workshops are offered that combine in one single day a lecture on an actual topic of chemistry research held by a chemistry researcher, a workshop acquainting the teacher to new pedagogies related to the topic given by a chemical educator, and a joint activity of planning a lesson from both sources within a group of teachers. Also trainings which combine a single set of events into a joint learning process proved to be more effective. An example will be discussed in the following section.

Evidence-based continuous professional development (CPD) courses

Effective professional development needs to provide an opportunity for teachers' reflection and learning about how new practices can be evolved from existing classroom practice. The 'evidence-based' approach consists of collecting of artefacts in a particular science learning domain that show teachers' work and students' learning, combined with written commentaries that explain the role of the artefacts within the learning context (Taitelbaum et al., 2008).

Ball (2004) refers to 'harnessing' recorded teachers' experience as a means for teachers' learning individually and collectively and creating shared professional knowledge. Such records of practice (evidence) enable teachers to examine their own instructional strategies and students' learning alongside their previous practice and those of their colleagues. The preparation of the evidence, and the reflection that follows it, can help teachers gain insights, evaluate goals, better understand the relationship between components of practice or events, and view them within a broader cultural, moral, and professional perspectives. Namely, the evidence and the activities associated with its processing foster the creation of a community of practice (Lave & Wenger, 1991). The process of collecting, explaining and justifying these evidence sources therefore helps in enhancing teachers' development towards accomplishment in their practice. Shulman and Shulman (2004) stipulate that

> an accomplished teacher is a member of a professional community who is ready, willing, and able to learn from his or her teaching experiences.' They go on to argue that the features of teacher development and so a necessary part of what a CPD program should provide are 'vision, motivation, understanding, practice, reflection and community. (p. 259)

One example is a course offered by the Weizmann Institute of Science in Israel. The course involved activities designed to directly develop teachers' skills in collecting, sharing, and reflecting on evidence in the domain of teaching chemistry using inquiry-type experiments. The goals of the course were:

- Improving the teaching strategies regarding using the inquiry approach in the chemistry laboratory,
- Improving inquiry skills,
- Promoting teachers' reflective thinking, and
- Creating a community of practice that shares their knowledge, difficulties, successes, and dilemmas.

The course consisted of a summer induction course and workshops conducted throughout the year. During the summer the teachers participated in an induction course (a five-day workshop, eight hours a day). During the course the teachers learned the inquiry skills by having first-hand experience in all the cognitive dimensions and the practical stages that accompany such learning. This included asking relevant questions, handling and solving unforeseen problems, designing experimental conditions to resolve research questions, working in small collaborative groups, and conducting experiments. They also experienced the use of various assessment tools that had been developed. During the school year the teachers participated in a workshop consisting of several meetings. Some of the teachers who participated in the course were videotaped while conducting inquiry-type experiments in their classes, and were interviewed immediately afterwards. The course followed the teachers' implementation at school as well as workshops conducted by experts in science education. As part of the course, the teachers brought artefacts from their classrooms and turned them into pieces of evidence, and wrote protocols assembled in a portfolio that were used to demonstrate evidence-based practice in chemistry teaching in the inquiry laboratory. Each piece of evidence revealed the teacher's professional development (PD) in a certain skill.

The outline for the contents and activities of the meetings during the school year are presented in Table 1. Each meeting consisted of the following parts:

- Elaborating on or introducing issues such as accomplished teaching, artefacts, evidence, portfolio, and reflection,
- Teachers' presentation of pieces of evidence about their teaching regarding the inquiry approach in the chemistry laboratory, and

Table 1. Content and activities of the evidence based CPD course

Meeting	***Content and activities***
1	1. Acquaintance between the teachers and the CPD providers 2. Presentation of the CPD program 3. A lecture: "The teacher as a researcher in his own class" 4. Presentation of the teachers' guide, including several inquiry-type activities 5. Personal perspective of an experienced teacher – reflection and its contribution to the teacher's practice 6. Outlines for the CPD program and the web forum that will be used during the CPD program ***Home assignment***: Write on the web forum your plan for the coming year. What experiments will be carrying out?
2	1. Discussion – the reasons for choosing to teach using the inquiry approach, from the teachers' point of view and in behalf of the students 2. Discussion – unique characteristics of the inquiry teaching 3. Watching a videotape – sensing how the classroom is managed during a inquiry laboratory session 4. Discussion of issues from the classroom raised by the teachers ***Home assignment:*** Write the teacher's personal background on the web forum
3	1. What do we mean by reflection? 2. What can be used as artefacts from class? 3. Discuss classroom issues raised by the teachers ***Home assignment:***Bring one artefact that demonstrates your skills as an inquiry teacher; insert some of the students' inquiry questions into the web forum; analyse on the web forum other teachers' inquiry questions.
4	1. Development of the concept of evidence and its structure, based on the teacher's presentation 2. What is a portfolio? Rationale, objectives, and structure 3. Discussion of classroom issues raised by the teachers
5	1. Presentation of a piece of evidence, followed by discussion and reflection 2. Discussion of classroom issues raised by the teachers ***Home assignment***: Construct a piece of evidence that demonstrates your skills as an inquiry teacher
6	1. Presentation of a piece of evidence, followed by discussion and reflection 2. Discussion – What changes occurred in my practice until now? 3. Plan regarding the next piece of evidence 4. Discussion of classroom issues raised by the teachers ***Home assignment***: Place on the web forum the pieces of evidence on which you elaborated.
7	1. Presentation of final pieces of evidence 2. Summary: What have we done throughout the CPD program 3. Discussion of classroom issues raised by the teachers ***Home assignment***: Elaborate on the portfolio and submit it within two weeks, as one of the course assignments.

Table 2. The use of a portfolio

Slide No. 1

What is a portfolio?
Port = Carry; folio = paper
Portfolio is used in different kinds of professions: painters, photographers, models, and writers.
The portfolio includes a collection of diverse materials over time that reflects talent and achievements.

Slide No. 2

The different kinds of portfolios
Three main kinds: Collection of the best selected items
A cumulative and ongoing collection of entries
A cumulative and ongoing collection of entries that are selected

Slide No. 3

Portfolios have been defined in different ways depending on their purpose, which could include certification and selection, appraisal and promotion, or the continuing professional development (CPD) of teachers

Purposes of a portfolio

The teacher may prepare a portfolio:
To apply for a position or promotion
To support a school appraisal process
For use in undertaking further studies towards an education degree, diploma, or certificate. To assist reflective practice, professional renewal, and identification of career and professional development goals

Slide No. 4

Issues concerning the portfolio:
The portfolio should present the professional development of a teacher throughout the year while teaching by the inquiry approach.
The professional development portfolio can include materials and samples of work that provide evidence of critical examination of teaching and learning practices
The teachers decide what pieces of evidence they are going to present, so they will reflect their professional development

Slide No. 5

What will be included in the portfolio?
Introduction
Professional Background
Three pieces of evidence
Reflective Summary on the CPD

Slide No. 6

Introduction
Presentation of the subject (or domain) chosen for the portfolio, its importance, and relevance for teaching/learning
Perceptions of the main ideas and concepts of the domain, teacher's beliefs about teaching/learning/evaluation

Slide No. 7

Professional Background: Education, teaching experience Previous in-service experience Other roles in school

Slide No. 8

Three pieces of evidence Each is according to the structure presented

Slide No. 9

Reflective Summary of the CPD What have I learned? Strengths and areas for improvement Implications regarding my teaching in the future Specific goals/ plans for further professional development

– Discussions regarding pieces of evidence, and the teacher's practice following each presentation.

An essential feature of the course was the construction of an individual portfolio, which included evidence of how teaching strategies had been implemented and how teachers reflected on their practice. Previous research that supports the potential of portfolios as a tool for enhancing learning and development has been widely reviewed and documented (Orland-Barak, 2005). The portfolio used for CPD purposes usually involves the selection of materials that provide evidence for critical examination of teaching and learning practices. The emphasis in portfolio development could be on the process of construction or on the quality of the product, and there are tensions between these two purposes that should inform the use of portfolios for CPD. Table 2 presents a power point presentation prepared by the teachers in the course, including explanations about the portfolio, and guidance for how to construct and use a portfolio.

As mentioned before, some of the teachers were videotaped while conducting inquiry-type experiments in their classes, and were interviewed immediately afterwards. Based on the findings, we concluded that the CPD programme contributed to the professional development of the teachers. The teachers became more reflective and more aware of their practice. In addition, it was observed a change in their pedagogical knowledge and content knowledge regarding the inquiry teaching. Moreover, their anxiety concerning the implementation of the programme was reduced significantly throughout the year. In other words, the evidence-based approach formed the catalyst for high levels of socio-cultural interaction between the teachers on the CPD program so that they were able to overcome the hurdles of implementing these new practices on their return to their schools.

Collaborative educational research and development for CPD

An even more interactive mode is involving chemistry teachers into the process of curriculum development and educational research. The following case on the topic of assessment in chemistry education from Israel may illustrate this.

The implementation of a wide spectrum of instructional techniques in the science classroom necessitates matching an appropriate assessment tool for each learning goal to measure the students' achievements and progress (Hofstein, Mamlok, & Carmeli, 1997). According to the NRC (1996):

> Assessment policies and practices should be aligned with the goals, student expectations, and curriculum frameworks. Within the science program, the alignment of assessment with curriculum and teaching is one of the most critical pieces of science education reform. (p. 211)

The need to match assessment tools to the learning goals has received support in studies conducted in chemistry by Ben-Zvi, Hofstein, Samuel, and Kempa (1977). Their work clearly shows that achievement in written exams is not highly correlated with achievements requiring inquiry abilities, which are manifested by laboratory work. Moreover, Shavelson, Baxter, and Pine (1992) compared multiple-choice tests with hands-on performance assessment and found that the correlation between these variables is only moderate. In a workshop accompanying a curriculum development process teachers were invited to become partners in the evaluation of the innovation (Mamlok-Naaman, Hofstein, & Penick, 2007). The focus was to whether the objectives of a new curriculum were accomplished. The workshop was initiated to address the questions: What strategies should we use in teaching Science and Technology (STS)-type modules, and how should we assess the students who are studying such modules?

The workshop participants consisted of 10 science teachers from 10 different high schools in Israel. Each taught the *Science and Technology for All* program in one class and had at least 10 years of high-school science teaching experience, mainly in grades 10-12. All of them had already participated in several in-service professional development workshops. The workshop participants met eight times, 4 hours every second week. Two science education researchers conducted the workshop and the research associated with it. They were experts in curriculum development and in the professional development of teachers. The teachers had already taught the *Science and technology for All* program previously mentioned but had difficulties in using a variety of teaching strategies in general, and in grading and assessing their students in particular. The workshop coordinators focused on guiding the participating teachers in using a variety of teaching strategies, and in the development of auxiliary assignments for their students, together with assessment tools. The assessment tools used in this workshop consisted of detailed checklists (rubrics) and rating scales.

The different components of the workshop covered:

– Discussions of the teaching methods,
– Preparation of learning and auxiliary materials and assessment tools,

I. **Critical reading of scientific articles published in newspapers or other media and original scientific articles published in scientific newspapers.**

Scientific articles published in daily newspapers and in scientific newspapers can serve as an important source for enrichment and for making the subject studied more relevant and up-to-date (Wellington, 1991). Scientific articles published in scientific newspapers can be classified as primary literature. The articles are originally written by scientists, more specifically, these consist of scientists reports on their research work, ultimately, being published in professional journals (Yarden, Brill, & Falk, 2001). In order to use them in high school, however, they should be modified into a popular, easily readable version. However, regarding daily as well as scientific newspapers, critical reading of articles is thought to contribute to developing a literate student in the sciences (Norris & Phillips, 2003). Each student in class had to choose an article from a collection of diverse articles provided by the teachers. The students were also provided with a written guide for critically reading the paper (Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005).

The articles given to the students dealt with the following topics: Important elements, The Discovery of the Rare Earth Elements, Chemistry in the Bible, Thermodynamics and Spontaneity, The Story of Energy, Chemical Aspects of Atmospheric Pollution, or The Special properties of the NO compound. For example, the following is a short description of the content of an original scientific article: Nitric oxide (NO)* acts as a single molecule in the nervous system, as a defence agent against infections, as a regulator of blood pressure, and as a 'gate keeper' of blood flow to different organs. In the human body it is thought to have a lifetime of a few seconds. Thus, its direct detection in a low concentration is rather difficult. The article reports on the design of a new electronic sensor sensitive to small amounts of NO in physiological solutions and at room temperature. The following are the stages of the detection process: NO binds to the surface area of the detection device (composed of an organic compound). The organic compound is attached to an alloy of GaAs (Gallium Arsenic), a semiconductor. As a result of the change in the surface, due to the binding of NO, the current flow in the alloy changes and is sensed by a detector. (Based on: Wu et al., 2001).

The article underwent a simplification stage in order to adopt it to the students' reading ability and to their chemistry background. For the purpose of simplification, the article was organised (and written) in sections, namely abstract, introduction, research methods, results, and summary. The introduction presented the needed scientific background. In addition, in the introduction, we also provided the students with a glossary of new and unfamiliar words, equipment, etc., such as semiconductors, and resistors. The research method introduces the students to methods that the scientists used in their work. At the end of the article we wrote a short summary containing the main ideas incorporated in the article. The results were presented on a graph that shows the different experimental conditions. The article was selected since we assumed that it presents a topic that could be characterised in terms of „frontiers of chemistry," as relevant, and as one that had a technological application. Thus, we thought that it would be of interest to the students. The students were asked to read the article and then to:

1. Identify at least five scientific concepts whose meaning is unknown to you.
2. Compile questions that raise criticism of the article's contents.
3. Answer the compiled questions.

II. Writing an essay focusing on scientists and their discoveries, entitled 'The person behind the scientific endeavor'

In order to help students in writing an essay about „The Person behind the Scientific Endeavor," the teachers introduced them to the biographies of numerous eminent scientists from different periods. These scientists developed scientific theories that often contradicted those that had been previously accepted. The students were asked to describe in detail the lives of these scientists and the discoveries made by them. They also produced work characterizing „their" scientists: a picture of the scientist accompanying an article that the students had written. The students used internet resources, and the teachers helped them with references dealing with the history of science (e.g. Conant & Nash, 1964; Priesner, 1991; Rayner-Canham & Rayner-Canham, 1998; Seybold, 1994). Afterwards, the class constructed a display along a time-line in order to place events, scientists, and theories in their appropriate historical perspective. Thus, all the students felt that each scientist represented by them had been given an honourable place in the history of science.

Figure 2. Examples of two assignments

– Development of rubrics – criteria for the assessment of the assignments,
– Analysis of samples of students assignments, and
– Improvement and revision of the rubrics according to samples of the students' assignments.

In the first three meetings, the participating teachers were exposed to lectures and to activities related to alternative assessment tools and methods, and especiallyto the way in which they should get used to working with rubrics. Each teacher prepared the assignments for his or her students (see examples in Figure 1), followed by assessment tools. The assessment tools included tests, quizzes, and assessment guides for carrying out mini-projects, writing essays and critical reading of scientific articles. All the assignments were developed in stages, each of which required consideration and an analysis of assessment criteria as well as scoring. These assignments were administered stage-by-stage at school. The students were involved in the assessment methods and their respective weights. This continuous assessment provided them with more control over their achievements, since they were aware of the assessment method, the weight percentage for each of the assessment components, and the final grade. At each stage, the students submitted their papers to the teacher for comments, clarification, and assessment. The students met the teachers before and after school for extra instruction and consultation. The detailed checklist given to each student after each assignment compelled them to address the comments with the greatest seriousness if, of course, they wanted to improve their grade. The students reflected on their work and ideas at each stage, and followed their teachers' comments on a detailed checklist and corrected them accordingly. Thus, they were able to improve their grades. The teachers revised the rubrics related to the assignments at each stage. Samples of the students' assignments were brought to the workshop for further analysis, involving both the coordinators and their colleagues the participating teachers. The group discussed the revision of the rubrics, and agreed on the percentage (weight) allocated to each of the assignment's components. They also agreed on the criteria for levels of performance in order to grade the students as objectively as possible.

Finally, the work of the teachers contributed to their CPD. But, the strategies and knowledge gained also helped to better understand the implementation process of the new curriculum.

Teachers develop and research their own practice by Participatory Actions Research (PAR)

Action research is a process of learning and changing, aiming at concrete practice. The analysis of practical professional situations by the ones who are acting in practice leads to an improvement of the current situation, further develops their own practical and theoretical competence in coping with professional situations and contributes to the broadening of the level of knowledge of the practical and academic community (Posch, 2001).

There is a broad range of different interpretations of action research. The most common criterion of diverse forms of action research is the role that teacher has to take, including the consideration of who has the actual power in an actions research project (Grundy, 1982). Emerging from rather research-oriented interpretations in the early beginnings of action research (Lewin, 1946), increasingly teacher-centred versions of this approach were established in the educational sciences by the 1970s (Altrichter & Gstettner, 1993). Therefore, Grundy (1982) and Carr and Kemmis (1986) differentiated between three different modes of action research: technical, practical, and emancipatory action research (Table 3).

Table 3. Three modes of Action Research in the means of Grundy (1982) illustrated by quotes from Masters (1995)

Technical Action Research	***Practical (or Interactive) Action Research***	***Emancipatory Action Research***
"The underlying goal of the researcher in this approach is to test a particular intervention based on a pre-specified theoretical framework, the nature of the collaboration between the researcher and practitioner is technical and facilitatory. The researcher identifies the problem and a specific intervention, then the practitioner is involved and they agree to facilitate with the implementation of the intervention."	"In this type of action research project the researcher and the practitioner come together to identify potential problems, their causes and potential interventions. The problem is defined after dialogue with the researcher and the practitioner and a mutual understanding is reached."	"Emancipatory action research promotes emancipatory praxis in the participating practitioner; that is, it promotes a critical consciousness which exhibits itself in political as well as practical action to change. (…) This mode of emancipatory action research does not begin with the theory and ends with practice, but is informed by theory and often it is confrontation with the theory that provides the initiative to undertake the practice. (...) The dynamic relationship between theory and practice in emancipatory action research entails the expansion of both theory and practice during the project."

Grundy (1982) has already stated that there can be movement between the different modes (Figure 3):

> The differences in the relationship between the participants and the source and scope of the guiding 'idea' can be traced to the question of power. In

> technical actions research it is the 'idea' which is the source of power for action and since the 'idea' often resides with the facilitator, it is the facilitator who controls power in the project. In practical action research the power is shared between a group of equal participants, but the emphasis is upon individual power of action. Power in emancipatory action research resides wholly within the group, not with the facilitator and not with individual within the group. It is often the change in power relationships within a group that causes a shift from one mode to another. (p. 363)

Action research starts with every-day reflection processes which are accompanying the acting of the practitioner. Its purpose is to shape these reflection processes in a more conscious and systematic way. Most of the time, it consists of several steps, which can run through several cycles of knowledge gaining and action improvement ("action research spiral"):
- Identification and definition of a problem,
- Investigation of the situation (its features, different points of views etc.),
- Development and realisation of strategies how to proceed, observation of their effects and side effects,
- Reflection on the realisation experiences, and
- New formulation of the point of view of the problem and development of strategies how to proceed.

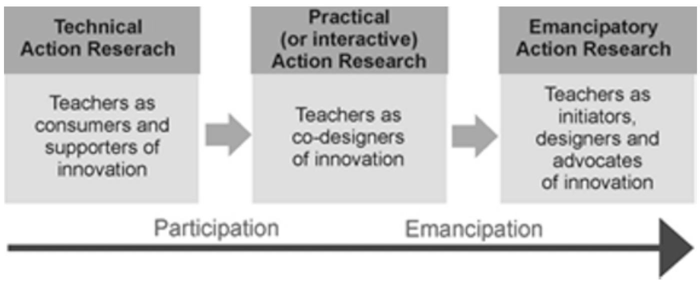

Figure 3. Structural development of action research

A specific form of action research projects developed in the last 10 years in the context of German chemistry education: *Participatory Actions Research* (PAR) in science education (Eilks & Ralle, 2002). This specific model proved explicitly how it is contributing to chemistry teachers CPD (Eilks & Markic, 2011; Mamlok-Naaman & Eilks, 2012). With respect to the objectives of chemistry education five equally important domains of objectives when using action research as a strategy are applied (Figure 4):
- The development of new concepts and materials for improving teaching and learning practices, including the evaluation and dissemination of said strategies,
- The attainment of empirical evidence on applied learning and teaching approaches within authentic teaching practice,

– The development of concrete teaching practices involved in the process of deficit reduction, and
– In-service training of the practitioners involved as pertains to their self-awareness of how effectively they work, including improving their skills in curriculum development and evaluation.
– Documentation of the settings and experiences as examples of good teaching practice.

In order to reach these five objectives, the PAR research model for science education is described as a cooperative process of practitioners and accompanying scholars. To achieve such research-based innovation, the cyclical model of brain storming, evaluation, reflection, and revision is applied. Any ideas for classroom innovation are continually compared to the evidence available from empirical research. In order to connect these two areas, relevant research evidence is presented to the teachers by the university researcher in a group discussion format. Empirical results are also compared to actual teaching experiences in the classroom and examined with respect to the needs and wishes expressed by teachers for their day-by-day situation in school.

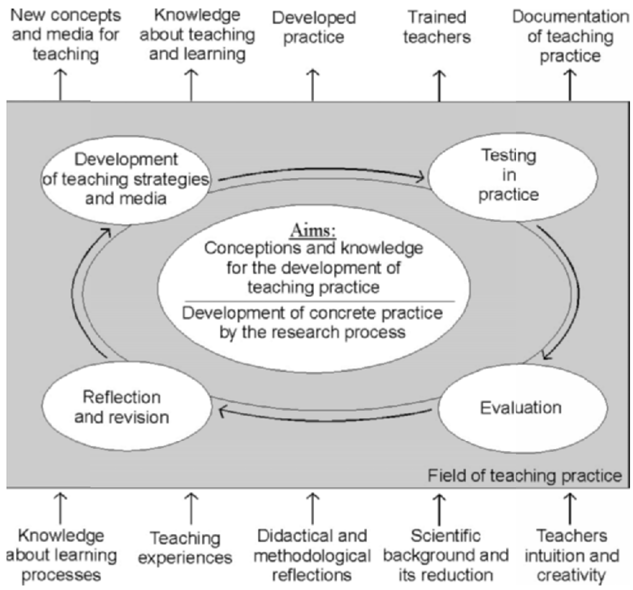

Figure 4. Research model of Participatory Action Research in science education (Eilks & Ralle, 2002)

In one example (Eilks & Markic, 2011), an original workgroup composed of six chemistry teachers has been expanded to a current total of 15 participants from various types of schools. The current members have widely varying professional qualifications ranging from 12 to over 30 years of teaching experience. For a time of more than 13 years up to now, about ten group members take a regular and active part in the monthly meetings. Of this core group, four teachers have been on board since the project's inception, four more joined within the first year, and the remaining two began in the second and third project years, respectively. The remaining five teachers are only loosely associated with the group. They come to the group's meetings only infrequently due to long travelling distances involved. The same university educator has accompanied the group over the entire 10-year time frame. In addition to the core members, student teachers and doctoral students from the university are involved as auxiliary helpers from time to time.

Over the years, a continuous shift in the teachers' attitudes and views on practice-research relations was observed (Eilks, 2003; Eilks & Markic, 2011). In the first year, the teachers viewed themselves mainly as technical supporters of innovation as described by Grundy's technical mode (Figure 3). The reason for this was due to their uncertainty about the level of trustworthiness and security to be found in the newly developed curricular and methodological approaches. Nevertheless, all of the teachers expressed their feelings that after the initial year that the new approaches had proven themselves better than the old ones. They saw definite advantages in the new approach which could be recognised in their change of practices. Nevertheless, the teachers still rely on guidance available through the external expertise of the science educator. But, now this can be seen as a thoughtful decision instead of an insecure or stop-gap reaction. Maybe now we can view the participants' increasing habit of self-reflection and growing decision-making abilities about when to follow and when to oppose particular changes as a successful contribution to the teachers' emancipation process (Mamlok-Naaman & Eilks, 2011).

SUMMARY: KEY SENTENCES

- Accomplished teaching of chemistry can be defined in terms of the knowledge which teachers use in their teaching. This knowledge can be categorised as subject matter knowledge (SMK), general pedagogical knowledge (PK), and pedagogical content knowledge (PCK).
- Due to a constantly growing body of knowledge in the profession of chemistry teaching, changing curricula and continuous changes in society professional learning of teachers is necessary. Teachers need continuous professional development (CPD).
- Traditional approaches to professional development are top-down, with low interactivity, and little less connection to teachers' needs and prior experiences. Traditional top-down approaches of CPD are limited in effect.
- Effective professional development is continuous (CPD), based on connecting innovation to authentic teaching experience, involves external support, makes the teacher an active part of the process, and focuses on teachers' re-constructing and developing teaching practices.

– Evidence-based CPD courses and action research are among the most promising strategies for teachers' CPD.

ASK YOURSELF

1. Describe with your own words what is meant by PCK, and how it is different from SMK and PK.
2. Make a list of quality criteria for effective CPD programs.
3. List all potential sources for traditional professional development.
4. Describe an example of a non-traditional CPD program.
5. Describe an example for a professional development activity which you experienced, and which was a good teaching experience.

HINTS FOR FURTHER READING

Abell, S. K. (2008). Twenty years later: Does pedagogical content knowledge remain a useful idea? *International Journal of Science Education*, *30*, 1405-1416. In this paper, Abel claims that PCK is very attractive concept, and it gives an organizer for thinking about the goals one has for science teachers: What do we need to know about themes science teachers? How can we help them progress as science teachers?

Gess-Newsome, J., & Lederman, G. L. (eds.) (1999). *Examining pedagogical content knowledge*. Dordrecht: Kluwer. The book discusses the concept of PCK, which is very essential to pre-service and in-service teacher education, educational policy, and educational research.

Osborne, J., & Dillon, J. (eds.) (2010). *Good practice in science teaching: What research has to say?* London: McGraw-Hill. The book discusses the needs of teachers to invest both in subject matter knowledge as well as in the nature of science and in science education.

Altrichter, H., Posch, P., & Somekh, B. (1993) *Teachers investigate their work: an introduction to the methods of action research*. London: Routledge. This book is a comprehensive guide how to use action research for researching one's own classrooms.

Taber, K. S. (2007) *Classroom-based research and evidence-based practice: A guide for teachers.* London: Sage. This book is a good resource for teachers interested in researching their classroom as part of their CPD. The book offers an overview on research methods; in particular it discusses what is needed before starting a classroom-based research project.

RESOURCES FROM THE INTERNET

RSC Learn Chemistry: *www.rsc.org/learn-chemistry/.* By using this resource from the Royal Society of Chemistry, the teacher can update his knowledge on chemistry and chemistry teaching as part of his CPD. The website reports new chemistry research, courses, networks, ideas, materials…

ASE: www.ase.org.uk/home/. The Association for Science Education (ASE) is the national science teachers' network in the UK. This resource can serve as an example of a national teacher association network, helping to find contacts, meetings, and initiatives for CPD. Respective associations are available in many countries and operated in a variety of languages.

CARN: www.esri.mmu.ac.uk/carnnew/. The Collaborative Action Research Network (CARN) is an international network of action researchers. Resources, conferences and activities are announced and exchanged via CARN and several regional hubs.

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CARMEN FERNANDEZ, JACK HOLBROOK,
RACHEL MAMLOK-NAAMAN & RICHARD K. COLL

11. HOW TO TEACH SCIENCE IN EMERGING AND DEVELOPING ENVIRONMENTS

The complexity of science education today, particularly the areas related to chemistry, needs new teaching approaches, new teaching resources, new skills of the teacher and an alternative focus for the subject itself. All of these factors need to be considered in the context of all countries of the world. In developing countries, there are still further challenges ahead, as teachers struggle to enable their families to survive and do not always have the necessary training, while schools are overcrowded, operating multiple sittings in a day and textbooks are few and far between, with new copies often too expensive to purchase. All too often in these countries, student-centred learning is a dream that is far from being feasible and assessment systems are a burden, serving to determine how the selected few students can progress, while ignoring the exciting challenges and intrigues from stimulating learning which the subject has to offer. Despite these problems, improving science education is often regarded as a priority for developing countries – the goal is nothing less than the capacity to apply learning, whether this is knowledge, skills or values, to new situations. This chapter addresses some of the issues currently facing science education in developing countries. In so doing it draws also on ideas expressed in earlier chapters of this book.

THEORETICAL BASIS

> *This unbalanced distribution of scientific activity generates serious problems not only for the scientific community in the developing countries, but for development itself.*
> (Kofi Annan, 2003, p. 1485)

Why teach chemistry in emerging and developing country environments?

Major changes have taken place in the manner in which science and technology function as part of society as we enter the 21st century. As suggested in a recent report from the advisor to the Prime Minister of New Zealand: "*There is no doubt that the role of science in modern society is changing. It is very different to that of*

I. Eilks and A. Hofstein (eds.), Teaching Chemistry – A Studybook, 299–326.

a generation ago" (Gluckman, 2011). The report draws attention to the fact that many of the challenges faced today are dependent on science, climate change (at the global level), or problems of environmental degradation, or enhancing economic productivity (at the local level). It suggests that while much less attention is given to science (or chemistry) which is associated with the providing of manufacturing products, much more is given to science being used to support decisions related to developments in society. This idea is also emphasised by Tytler (2007):

> There is a need for science-savvy citizens not simply in the science and technology workforce but in government and industry generally where science-related policy and decisions are made. There is also a need more generally for science-savvy citizens who deal increasingly with science and technology artefacts and issues at a personal and a public level, and directly influence policy through their responses and concerns. (p. 19)

In the New Zealand Council for Education Research report (Gluckman, 2011), the author highlights the observation that science education now has several distinct objectives. The first is to accumulate knowledge in a traditional sense, called pre-professional education, which provides students with the knowledge in subject areas such as physics, chemistry, biology, and mathematics that will allow them to enter tertiary education. The other three are named citizen-focused objectives and are related to (a) practical knowledge of how things work, (b) knowledge of how the scientific process operates and acquiring a level of scientific literacy, and (c) knowledge of scientific thinking as part of their development of general intellectual skills in order to distinguish reliable information.

Thus, in turn, these documents point to the need for a realignment of science subjects, such as chemistry, which are taught in school and the need for a more urgent consideration of this, bearing in mind the traditional slow pace of developments in the sphere of education. It suggests less attention needs to be given to the acquisition of facts and explanations of the past (noting that the Internet is far more capable of supplying the data needed when called upon to do so), but more emphasis be placed on the ability to develop the capability to function in society. This inevitably relates chemistry to a more socio-scientific role than has been the role hitherto (Tytler, 2007).

With the above in mind, an important question, which all countries, but especially emerging and developing countries, need to face, is: Why teach chemistry (science subjects)? To consider this, an important starting point to be accepted is that the rationale for teaching chemistry in school is that its purpose cannot be divorced from the goals of teaching in any subject and hence from the goals of education as a whole (Holbrook & Rannikmae, 2007; Sjöström, 2011). Of course, the substance of chemistry, its content, laws and theories are very specific to the subject, but the purpose of acquiring these, or why one set of content, laws and theories, as opposed to another, is put forward, is based on the underlying educational attributes to be developed. Should a capability to participate in decision making within the community in a responsible manner be very much intended, then this value needs to be included in the education system and hence needs to be a feature of chemistry teaching. In this case, the learning of chemistry needs to be seen as enabling citizens to make informed decisions drawing on their chemistry learning and to be able to apply this in tackling community issues (Hofstein, Eilks, & Bybee, 2011; Holbrook, 2005). This paints a far different type of chemistry course than that which has been familiar to many chemistry teachers in the developing world.

So let us return to the question "Why teach chemistry?" It is suggested there are four separate developmental components, affecting all countries of the world, to which education and hence chemistry teaching, needs to embrace or reject. These have been identified (Driver, Leach, Miller, & Scott, 1996; Turner, 2008; Symington & Tytler, 2004; Tytler, 2007) as (a) enhancing democratic development, (b) supporting economic development, (c) promoting skills development, and (d) the need for cultural development.

While these four components are not mutually exclusive and elements of all can be argued, especially in the case of the teaching of chemistry in developing countries, the major focus for the teaching of chemistry needs to be related to the relative importance of each within the society. And here the focus for emerging/developing countries needs to be carefully considered at a political as well as an educational level. The curriculum, teaching and assessment system for education, in general, need then to be oriented accordingly. This chapter examines the intentions related to each of these components, focussing in particular on the needs of developing countries.

Teaching chemistry for democratic development. The democratic purpose of science education ensures that the students develop a confidence about science which would enable them to be involved in scientific and technological issues as they impact on society (Symington & Tytler, 2004). In promoting a major focus on democratic development attributes to be promoted through chemistry teaching can be expected to relate to: capabilities in consensus making, such as in classroom debates conducted among students geared to making decisions, and inclusion, in the teaching of chemistry, relevance for all students studying at a particular grade level. Other attributes are: tolerance of the views of others in developing reasoning or argumentation skills, motivation for action whether this is undertaking an investigation, studying a topic, or participation in an activity, promoting the common good, which is a democratic element of education for sustainable development appropriate for all within a society, a particularly relevant consideration when viewed for the developing country point of view and so on (Holbrook, 2009).

In such a context, chemistry content clearly needs to relate to the society. Rather than placing a heavy focus on the fundamental building blocks of matter (atomic structure, bonding, submicroscopic viewpoints, etc), there is a need to establish the importance of chemistry in the day-to-day functioning of society (Hofstein et al., 2011). Thus, the concept of polymers and the way they are used, the chemistry of materials, foodstuffs, medicines, and aesthetic elaborations, all part of everyday life, need to be understood from a safety, or health risk point of view, and its potential impact on the way of life in terms of its quality. This impact on the way of life may be immediate, discarding versus recycling of waste, or sustainability versus non-sustainability for the future, sustaining adequate, or maybe better, alternative sources, or recognising the pollution, aesthetic or derisive impacts on some sectors of the community compared with others. It also needs to look into the future where sustainability in developing or emerging countries relates to poverty alleviation, combating disease, environmental protection, recognising safety issues, all within a frame of development (Burmeister, Rauch, & Eilks, 2012; Holbrook, 2009).

This call for chemistry learning for all and the associated cognitive learning, the need for personal development and the social functioning associated with interactions within a community, all come together with a focus on the society (Holbrook & Rannikmae, 2007; Hofstein et al., 2011). The materials we choose to use, the way we use them, the suitability of their source and the ways in which they can be discarded in a safe and aesthetic manner can be expected to form a major focus of chemistry teaching. Indigenous materials can be expected to form a key aspect of learning, especially if contrasted to the ever invading use of manufactured polymeric substances such as 'plastics,' artificial fibres, soil chemistry and materials used by the building industry. In addition, the chemistry of foodstuffs, the formulation and use of medicines and the health risks associated with the abuse of substances such as alcohol, drugs, tobacco and the like, are all within the focus of chemistry teaching highlighting relevance. But, the learning is unlikely to be confined to substances. Physical chemistry aspects also need to be considered, especially aspects such as rate of reaction, solubility related to various solvents, conditions affecting reactivity, or increased yield and the concept of a catalyst. The description is not intended to be exhaustive, but to point to a heavily society-oriented learning focus enabling students to appreciate the important role of chemistry in everyday life and how chemistry can be expected to be included in socio-scientific decisions made by the citizens in a democratic country (Sadler, 2011).

Such an approach inevitably has extensive implications for teaching and learning. Materials, the phenomena they exhibit and the changes made possible within society form the backdrop for investigations, the solving of problems or the making of decisions. The learning can be expected to build on the familiar and hence lends itself to a strong constructivist approach (see Chapters 4 and 7; Holbrook & Rannikmae, 2010). Inquiry-based teaching (see Chapter 6) can be approached in a student-centred manner using materials found locally while the conceptual area of chemistry selected to take account of the local availability of materials and familiar processes. And of course, student involvement can be highlighted by the students playing a major role in the acquisition of indigenous materials, the setting up of relevant investigations and seeking the intended explanations.

Teaching chemistry for economic development. This is the traditional rationale for the teaching of science, and hence chemistry, in school. It focuses on developing the chemistry learning to form a suitable platform for the next level of schooling and eventually for pursuing chemistry at the tertiary level, or in a career. The development of high conceptual understanding in the area of science and technology is expected to play a major role in enabling the development of persons with expertise, which can be utilised for the economic development of the country (Bradley, 2005; Symington & Tytler, 2004). Thus, in promoting economic development, the emphasis in chemistry teaching is very much on conceptual understanding, both at a concrete and abstract level, based on creative and critical thinking, as well as problem solving abilities, both in a practical and a mathematical sense.

With an emphasis on economic development, the teaching is likely to start from aspects seen as fundamental. In chemistry, this is likely to be topics such as the particulate nature of matter, the manner in which the atoms and molecules interact and the creation of explanatory models that can be constructed. From such a base, often submicroscopic and hence abstract in nature, the chemistry teaching builds towards enabling students to conceptualise more complex, or abstract ideas, leading to cognitively demanding analytical thinking, evaluative judgements and synthesis of chemistry laws, explanation of chemical theories and an appreciation of the nature of science, of which chemistry is a part.

With such an approach, the teaching ideas build on one another; concrete experimentation gives way to the recognition of laws, or the formulation of theories and often the undertaking of mathematical calculations. The chemistry becomes more and more isolated from the society and into a direction, albeit exciting, of new developments, new approaches, new materials and new processes or mechanisms (De Vos, Bulte, & Pilot, 2002). It seeks to form an academic elite band of students, often strong on the abstractions in the textbooks, but poor on the transference of the ideas to new or societal situations. It is in fact a pathway appreciated by scientist as guiding students to become the next generation of scientists (chemists).

Clearly the economic approach, although advantageous for some students (and based on this, also advantageous for the economic development of the country should this expertise be usable within the country), is not suitable for all students. It is an approach that distorts the education goals in favour of conceptual overload and one that has a tendency to neglect the development of the person as an individual and functionality as a member of society (Holbrook & Rannikmae, 2007; Hofstein et al., 2011). For many students the learning is largely irrelevant to their lives, or their future aspirations.

A further factor very much of concern in emerging and developing countries is that for students guided to follow such a path, the materials and resources required are much more expensive, special facilities in terms of laboratories and apparatus are needed and textbooks have a speciality component increasing book size. There is also a tendency for content overload, as new developments are added to content already existing, and with this the teacher temptation to: (a) ignore student centred teaching approaches; (b) teach without concern for the pace of expected learning, or operating within the zone of proximal development appropriate for the students, that is, the learning or the challenge is within the ability to cope in the given support circumstances; (c) eliminating the seeking of evidence first-hand (practical work) largely because it is time consuming and does not play a major role in determining external examination grades, and (d) determine the level of learning solely through written summative-type examinations. As Symington and Tytler (2004) argue:

> This image of the school curriculum as a launching pad into a complex and highly contextualized future, rather than the creation of a certified knowledge bank, raises considerable challenges for teachers, curriculum writers and policy developers. The two images need not be contradictory, however, the lack of concern with specific knowledge building on the part of the interviewees, and the questions raised of the usefulness of particular knowledge over a life span, provide a challenge to how we might think of knowledge within a scientific literacy oriented curriculum. (p. 1415)

As contended above, the economic argument is based on the need to provide a science-trained workforce to support the advancement of the country. However, while this is a critical issue facing developing countries, research demonstrates that a modern, emerging economy needs 'science aware' citizens, not just employed in the science and technology workforce, but in government, commercial enterprises and the local economy generally, wherever science-related policies and decisions are made. In addition, there is also a need, more generally, for 'science aware' citizens to deal with issues at a personal and a public level, and in so doing, directly influence policy (Symington & Tytler, 2004; Tytler & Symington, 2006). An economic development only policy within a developing country would seem unwise. This is also true for developed countries where the students show a decreased interest in science careers mainly because much of the science taught in the schools is not directly relevant in everyday life, and many students do not achieve sufficient understanding of it to be able to contribute to scientific debates (Gluckman, 2011).

Teaching chemistry for skills development. In an agricultural or manufacturing economy, the need for labour with well-developed operational skills is important. This is not only from the manipulative perspective, but also the need to link this to an understanding of the processes, a concern for personal safety and ensuring the welfare of others.

For skills development, important attributes within chemistry teaching are seen as an awareness of handling equipment and apparatus in a meaningful, safe and efficient manner, collaborative teamwork, inquiry-based education leading to problem solving skills and the placing of an emphasis on a product-based education (Shwartz, Ben-Zvi, & Hofstein, 2006; see Chapter 6). Within chemistry, this lends itself to the carrying out of experimentation, possible through making equipment and the production of new substances, such as conversions in organic chemistry, or varying the conditions to maximise yield in reversible reactions such as sulphuric acid or ammonia production.

The teaching in a skills development curriculum emphasis is on student handling experimentation and project work and enabling the students to work in a collaborative manner, developing expertise in the handling of equipment and in operating in a safe and efficient manner. It is intended, but usually much more difficult for teachers to realise, that students acquire: (a) conceptual understanding underlining the experimentation, (b) the ability to determine the need related to experimental repetition, (c) dealing with factors or variables impacting on the process, and (d) determining the manner in which results should be presented (for example, considering number of decimal points recorded for specific conditions or arising from calculations, the drawing of suitable graphs or the formulation of meaningful tables).

Skills development clearly has a role in the teaching of chemistry, but unless it promotes a capability to function in unknown situations, which are likely to arise in the future, the skills are designated for the country's operations of today and are in danger of hindering developments for the future. A skills development emphasis for a curriculum is thus not seen as appropriate for developing countries, although there is always a temptation to point to the high need for technical grade expertise as the country develops. For chemistry teaching, the skills development is best seen as an important sub-set of the democratic development, or the economic developmental thrust.

Teaching chemistry for cultural development. Where the teaching tries to stress national identity, the teaching of chemistry can be expected to be developed in the national language and put emphasis on local indigenous development, social practices and norms within the county, since the local backgrounds and contexts are not always Western, as it is in many textbooks (Malcolm, 2007). Within the teaching of chemistry, students can be encouraged to visit local industries and interrelate this with similar processes within the school course (Hofstein & Kesner, 2006). However, while the chemistry curriculum can be widened to explore materials used by artists, such as painters, the creation of sculptures or other decorative process such as in ceramics, glass making and the development of paper, the cultural development in chemistry teaching is usually more related to the development of social values. The chemistry thus emphasises traditional, indigenous processes such as the dyeing and weaving etc. of cloth, together with its comparison with artificial fibres; the use of local materials and their historical developments within society, such as soap making, cooking and preservation of food processes, obtaining clean water and the preparation and usage of traditional medicines (e.g., Kostka & McKay, 2002; Mandler, Mamlok-Naaman, Blonder, Yayon, & Hofstein, 2012).

A major factor to consider in the teaching of chemistry is the availability of materials and equipment. By emphasising local indigenous developments, this aspect is much more easily addressed. It relates the learning to the society and although causing a problem in that there is a need to break down the complex situations for the conceptual level of the students, this does enable a spiral approach to the teaching of chemistry. Sadly the issue is with how far such teaching can develop capabilities for the transfer of the conceptual and problem solving learning to new developments that are part of the 21st century world. There is also the motivation of students to consider, often attracted by the new advances in technology and their greater willingness to embrace these and engage in learning developments related to the future.

A cultural development approach can thus be seen to have merits in the developing world and can be expected to be part of any chemistry curriculum, but the demands for advancement in modern societies suggests that this approach is not one that can play the major role. It is again a sub-set, and in more rural areas, it is perhaps a key part of the democratic development approach.

Figure 1 shows a comparison of the main features associated to the four interrelated development components of education, focusing more specifically on the chemical education context.

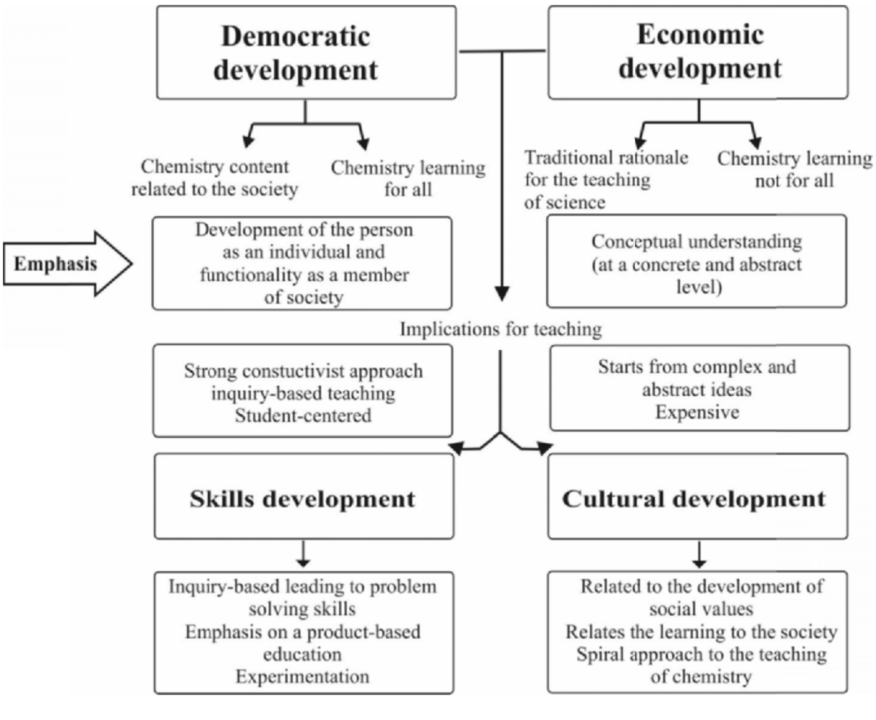

Figure 1. Main features of the chemical education developmental components

Teaching chemistry for utilitarian purpose. Symington and Tytler (2004) suggested a 5th developmental area, which they names utilitarian. It is designed to ensure that all members of society have sufficient knowledge of science to enable them to operate effectively and critically in activities where science can make a contribution to their personal well-being. However, it is suggested that this heavily overlaps with the democratic approach, adding a personal dimension to the functioning within society. It can also be taken to be adding a personal aspect to a skills or cultural developmental thrust.

Whichever direction is favoured, or perhaps more meaningfully, which direction receives the major emphasis (as all aspects can be incorporated), the teaching in school cannot be thought of solely as chemistry content, plus a series of unrelated concepts in a traditional concept map. Teachers need to recognise that it is the old approach, even if they, themselves, were taught in this manner. On the other hand, to develop student capability, be it in an intellectual, aptitude, or social orientation, the conceptualisation of ideas and theories will be an essential part of chemistry teaching.

Which emphasis for chemistry teaching in a developing country? All together, the important aspect is that the goal for chemistry teaching, even in developing countries, is not merely conceptual chemistry. The goal in school is nothing short of 'education through chemistry' (Holbrook & Rannikmae, 2007). The chemistry becomes the vehicle to promote the attributes as indicated above so that the learning relates to a capability for the future unknown, rather than simply an ability for today's world; it relates to doing rather than memorising; it relates to solving new situations, not understanding the isolated chemistry ideas. And above all, the learning must relate to society. The chemistry learning is socio-scientific, not chemistry isolated from society (Holbrook & Rannikmae, 2010; Hofstein et al., 2011; Sjöström, 2011). Unfortunately, schools of the past have built up barriers, isolating the learning from that which relates to the society (De Vos et al., 2002). The learning becomes sterile; having little value for the common good of the society and this fact turns students away from science. This is especially dangerous for developing countries.

A democratic emphasis for the teaching of chemistry is clearly designed for all students irrespective of their future career plans. It is relates chemistry with everyday life. On the other hand, the economic approach takes chemistry as an intellectual exercise in its own right and is much more clearly designed for students who wish to further their studies in the area of chemistry. Fensham (2008) argues for two different types of courses: one that is general and focuses on chemistry for functionality in society and the other, which is more academic and sees the subject of chemistry as the main focus learning area, albeit in a wider sense than pure conceptual content.

Whether two courses are a useful approach in developing countries, where examination success may well determine a student's future rather than the interest in a particular subject, is more debatable. A more meaningful approach recommended here is to focus the chemistry course on the democratic lines, but increase the conceptual challenge in line with the abilities of the students. In this way, the democratic focus takes a more humanistic approach, includes social values, but is not expected to compromise on the intellectual demands (Corrigan, Dillon, & Gunstone, 2007).

The context for chemistry education in developing countries

Irrespective of whether the context is a developing or developed country, relevant educational questions are: What are of importance for students to learn, what teaching approaches are valuable and in what ways is it useful to determine teaching/learning success? (Krugly-Smolskaa, 1990). As suggested by UNESCO (Delors, 1996), learning is expected to cover: learning to know, learning to do, learning to be, and learning to live together. Nevertheless, decisions about the kinds of science education that should be promoted need to be articulated with respect to specific educational policies pertaining to the population as whole and also any policy on science and technology which is associated with particular economic development strategies. In putting forward clear goals, four key issues, in general, are central to the nature of the teaching and learning experience offered by school chemistry:

- The type and format of the curriculum,
- Assessment strategies and emphases,
- Appropriate pedagogies (the practice of chemistry teaching), and
- An effective teacher supply including professional development.

The first three aspects will be discussed in the context of this chapter while the fourth aspect is discussed in detail in Chapter 10.

Type and format of the curriculum.

Amongst teachers, science educators, curriculum developers, and others engaged in the development of the intended school science curriculum or in its classroom implementation, there is a growing concern about the effectiveness of the existing curriculum, and its appropriateness as part of the core curriculum. Many countries are currently in the process of curriculum reforms, which are grounded in concepts such as science for all, promoting competences or capabilities, constructivism, and equity, and they focus upon the nature of science, science as inquiry, scientific applications, and relevance such as links to students' daily lives (Krugly-Smolskaa, 1990; Shymansky & Kyle, 1992). A further issue is the incorporation of education for sustainable development (ESD) (Burmeister et al., 2012) and its meaning in the developing country context.

In general terms, the role of the teacher is to teach the students. And in so doing, it is important to realise that it is not actually what the teacher does that is crucial, but what the students are capable of doing after teacher guidance. How can students construct in a constructivist manner if the teaching does not build on their prior learning? How can the students be given a chance to be creative, or think critically, if the teaching is not student centred? All the earlier ideas in this book have required the students to be active learners (see especially Chapter 7). This also applies to developing countries and this means students need to be involved.

They need to construct their thinking. And as each class is different, it is clearly impossible for the curriculum, whether set nationally or by the school, to be written for each particular set of students. The teacher must adapt. The teacher must judge. The teacher must ensure his/her students are learning in a meaningful manner.

Unfortunately, especially in emerging and developing countries, teachers are not always prepared to deal with the teaching and learning process in a student-centred perspective. And for developing countries, there is a need to shift the curricula to a focus more grounded on the everyday lives of its populace, with the core subject of science (or perhaps called science and technology or adopting an approach introduced by NRC (1996) and referred to as STEM – science, technology, engineering and mathematics) taking a societal direction. This may be equally relevant for emerging countries because the choices made in order to develop the country necessarily passes through decisions dealing with environmental, ethic and technological issues that only a democratic emphasis can provide.

Curricula such as recently developed in Bangladesh (NCTB, 2004) see specific objectives of science teaching geared to promote learning in terms of intellectual, moral and spiritual, communicative, aesthetic, social and cooperative, personal and physical attributes. This emphasis is related to seeing science as a core subject in the curriculum geared to all students irrespective of their future aspirations. Furthermore, this set of general objectives sees the learning across subject disciplines in a similar focus. In the same direction, according to Brazilian federative curriculum guidelines, the emphasis for secondary education focuses on the following premise: intellectual autonomy and critical thinking, preparation for the next level of schooling, preparation for professional life, and functionality as a member of society. Also contextualised and interdisciplinary approaches are recommended (Ministerio da Educacao, 1996, 1999). These emphases combine both attributes from democratic and economic development approaches as previously described, but since the goals are very broad, problems exist in their implementation.

These reforms suggest a change of focus away from a solely chemistry conceptual content and recognise a wider vision for science education and as such represent a major shift in intention and a significant change from the current prevalent practice in most situations in developing countries. Although the structure and nature of science curricula in the developing countries has largely followed trends designed by and for the developed countries, there are signs that developing countries see it important to address the relevance of their programmes to the different contexts, the availability of resources (learning and teaching materials, laboratories, equipment), assessment, and the appropriate training of science teachers' to support such intended changes.

In Table 1 there is one example of a didactic sequence, developed in Latin America, which may serve to illustrate how a more democratic thrust can be developed in chemistry teaching. The lesson tries to focus on a problem facing society, in this case *Back lagoons – are they recoverable?* and is designed to be part of chemistry teaching for 15-17 year old students. The lesson is centred in the Ecuadorian Amazon region, where a successful project had managed to extract petroleum oil, spread over 300 pits. This oil had resulted from 50 years of hydrocarbon exploitation by multinational companies, but without taking into account the concept of protection of the environment as part of their responsibility. The script focuses on the implications of this. The suggested science (chemistry) concepts to be acquired through the learning are identified with:

– Hydrocarbons: their composition, properties, refinement methods and transport,
– Fuels, lubricant oils and asphalts, and
– Techniques for the hydrocarbons recovery.

Learning outcomes are put forward to focus the learning by students (although there is obviously scope for modification). The intention in using this module in the teaching of chemistry is that the learning outcomes to be achieved by students are matched by specific activities as shown in Table 1.

Table 1. Example to illustrate the teaching of conceptual chemistry within a social context, allowing social issues to be integrated into the teaching

Learning Outcomes	***Achieved by***
1. Decide, based on an analysis of the income-yield capacity of the project the change in social conditions and the environmental aesthetics, whether the project should go ahead. (Social values development)	Search of relevant, actual and detailed information Obtaining information from the field trip
2. Investigate and collect information from books and other secondary sources on contamination caused by petrol and ways to recover hydrocarbons. (Science process skill development)	Analysis of the feasibility and cost of the experience in Ecuadorian Amazon
3. Devise and present strategies for the hydrocarbons recovery, applicable to their region. (Further science process skill development)	Analysis and decision of the applicability, in the area, of methods to recovering of hydrocarbons
4. Communicate in oral and written form. (Enhancement of science communication skills)	Groups presentation of the results and make a common decision
5. Cooperate as a group member. (Enhancement of teamwork skills)	Groups and general discussion Elaboration of final report
6. Explain the contemporary problem of environmental pollution caused by hydrocarbons in terms of type of hydrocarbons, recovery techniques and usage of hydrocarbon products, proposing profitable solutions and applicable to their region. (Science conceptual learning)	Group discussion Elaboration of criteria to inform results

Issues associated with textbooks. It is recognised that many teachers are likely to have been educated in a traditional curriculum, where facts were delivered to students. For these teachers it is a major challenge to change to a more student-centred approach. This is particularly relevant for developing countries where teachers may have gaps in their formal education and many do not have formal teacher education, or do not have formal education in the area in which they are teaching (OECD, 2006). In this scenario, curriculum materials have an important role and many teachers are expected to follow the curriculum prescribed in textbooks. Even though it is urgent to deal with teacher education issues in developing countries, having good didactic materials which include a wide repertoire of activities can be expected to provide much needed assistance to teachers, especially those facing problems in their classrooms. Therefore, teaching materials have an outstanding role in developing countries particularly if there are insufficient chemistry teachers with formal teacher education. Unfortunately, even though there are many good curriculum materials which can be accessed on the internet, they are generally in English and so do not represent an option for teachers in developing countries who are not English speakers. It is well known that textbooks drive the enacted curriculum, even though local issues are hardly entertained, especially if these relate to social or personal contexts. Nevertheless, noting the investment made in textbooks in most emerging and developing countries, it seems worthy of further comment even if this is only to stress the need for greater investment in professional development.

In general, textbooks tend to promote the economic view of chemistry education, placing emphasis on the content rather than context. The sequence usually follows that indicated in the intended curriculum and indicates the learning within the curriculum without any specific regard to teaching time available. In this manner, as can also be said of the intended curriculum, the textbook is designed for the hypothetical student taught by the hypothetical teacher in a hypothetical school. It is left to the teacher to utilise this resource for real students and hence the value of teacher materials such as that illustrated in the previous section.

Thus, the textbook is one source of teaching resources, even though one that has much value especially if checked for acceptability and made available to the school, often through teacher choice of a number of textbooks on offer. For example, in the Brazilian context, the government has a national programme of textbooks, where an evaluation of books on the market is carried out. In many countries, such as Brazil, only textbooks that comply with a series of requirements are selected and made available to schools. Schools request their selected textbooks from a list made available by the ministry of education every academic year (Corio & Fernandez, 2010). This choice is usually made by the coordinator and the chemistry teachers in each school. The books are then sent to the teachers for distribution to all students in the school.

These textbooks may have different proposals on how to promote the teaching of chemistry and, where the curriculum, such as in Brazil is not mandatory; teachers and schools have some degree of freedom to work with their students. Unfortunately, even though this freedom exists, most teachers follow their textbooks because it is an easier option and/or because it is a valuable guide due to gaps in teacher education. Alas, because of these teacher gaps or lack of self efficacy, the curriculum which is delivered to the students is all too likely to be undertaken in a more traditional way, teachers feel safer than attempting student-centred teaching through a democratic type approach.

Based on the scenario illustrated in the previous paragraph, the need for extensive teacher education is a reality that developing or emerging countries such as Brazil must face, both with further in-service teacher professional development as well as the initial pre-service teacher training. In the meantime, it is necessary to continue the development and distribution of curricular materials which can help teachers already in the classroom to recognise alternative teaching approaches. In this direction a number of initiatives can be undertaken. In Brazil, on-line courses are made available for in-service teachers, additional curriculum materials are put on the Internet, science courses can be viewed on television, science journals are produced for teachers with a range of student-centred activities proposed, in-service teacher meetings are spread across the whole country usually linked to the local university and activities are provided in science museums, just to mention some examples.

In conclusion, even though curricular reforms are advancing in developing countries, with curricula based on modern theories of teaching and learning, without teachers who can actualise these in the classroom, little development is likely to occur. Efforts need to focus on enhancing the quality of the initial training of teachers and ensuring effective in-service professional development is promoted. In Bangladesh, for example, where a new style of external examination questions have been introduced, and it was seen as important to ensure teachers understood the change of emphasis, it is recognised that a cascade model (whereby a few teacher are trained by experienced professionals and then these teachers train others and so on down the chain) of in-service teacher support was ineffective. An alternative model is promoted, which was to train as many teachers as possible using the experts and then, only utilising teachers as additional trainers where they had shown sufficient interest and expertise. This proved a more effective model, even if the pace at which teachers received the in-service support is slower.

Education for sustainable development. While Chapter 1 of this book already introduced this term, it is worthy of further consideration in the developing country context. The *UNESCO Decade of Education for Sustainable Development* (2005-2014) is oriented to promoting education *for* sustainable development to ensure sustainable lifestyles. And to promote such lifestyles (OECD, 2005), competencies to be promoted within the DeSeCo (Definition and Selection of Competencies) frame are classified as:

– Subject competencies – knowledge, facts, definitions, concepts, systems,
– Methodological competencies – skills, fact-finding, analysis, problem-solving,
– Social competencies – communicating, working interactively, citizenship, and
– Personal competencies – attitudes, values, ethics.

It is perhaps not surprising that these competencies relate very closely to the democratic view of education.

Nevertheless, there is no suggestion that sustainable development concepts are taught separately or taught within one of the four competences, but approached through systems such as: ecosystems (environmental diversity), economic markets (supply and demand) and social systems (society and its actors) as and when these impact on the science (chemistry) teaching, especially through an integration of these systems approached through examples, such as carbon trading (economic/environment), the impact of human capital on scientific and technological developments (economic/social), and the impact of fuels on transport systems (social/environment). However these examples may not necessarily well relate to the teaching within science (chemistry) education in a given country.

A well-known definition of sustainability and sustainable development is: "*sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*." (WCED, 1987 – World Commission on Environment and Development, referred to more informally as the Brundtland Commission). However, an alternative meaning can be (Barboza, 2000):

> the will to follow a rational approach to economic administration and the creation of economic policies; to manage public matters efficiently and predictably; to show respect and progressively to evolve towards democracy – the full participation of all concerned actors, while taking into account specific local circumstances. (p. 71)

This viewpoint sees democratic values as important within sustainable development (Holbrook, 2009). Going further, Sumner (2008) suggests that sustainability involves a set of structures and processes that build the civil commons. From this basic understanding of sustainability, values within the society play an important role. Civil commons is based on values that promote life first and foremost. This suggests these values related to being:

- Co-operative, rather than competitive, and
- A human construct, not a naturally occurring phenomenon, and by definition, built by human agency.

It might be useful to reflect on the implication of this towards:

- Norm referenced (as opposed to criterion referenced) assessment of students (setting up a competition between the students),
- Approaching the teaching of science from a personal or societal perspective rather than from scientific phenomena, and
- Giving attention to personal and social educational development, promoting this with a cognitive challenge that leads to both the development to problem solving (seeking the scientific solution) and decision making (the place of science within societal systems).

Actually, more general examples of the civil commons surround us every day: public education, healthcare, environmental legislation, health and safety regulations, and public broadcasting. It is civil commons that is at the heart of a values view of sustainable development. It is suggested this view incorporates a number of sub-themes of importance in developing countries, all having the potential to be strongly related to chemistry teaching – food scarcity, poverty alleviation, HIV/AIDS, and empowerment for peace.

Chemistry education can be expected to play an important role in the major sustainable development issues for education. From the education perspective, Ospina (2000) suggested the following items were important for ESD:

- Seek understanding, to anticipate, to imagine and to contextualise,
- Develop to the maximum, the potential of all, throughout their lives, so that they can achieve self-fulfilment and full self-expression with the collective achievement of a viable future; effect change in value systems, behaviour patterns and lifestyles necessary to achieve sustainable development, and ultimately democracy, security and peace,
- Disseminate the knowledge and skills necessary to foster sustainable production and consumption patterns and to improve the management of natural resources, agriculture, energy and industrial production,
- Ensure an informed populace, prepared to support changes in other sectors conducive to sustainability,
- Valorise aesthetics, the creative use of the imagination, an openness to risk and flexibility and a willingness to explore new options,
- Assert the importance of local communities and their ties to the entire earth and indeed with the universal,
- Identify and pursue new human projects in the context of a planetary consciousness and a personal and communal awareness of global responsibility,
- Engender new hopes and ways of channelling the valuable energies and resources of entire nations,
- Reach a stage in which the possibility of change and the real desire for change are accompanied by a concerted, active participation in change, at the appropriate time, in favour of a sustainable future for all,
- Promote a culture of citizenship and give value to social actors (such as non-governmental organisations and other sub-groups),
- Mobilise society in a concerted effort so as to eliminate poverty and all forms of violence and injustice that jeopardise the future and the maintenance of a good quality of life, and
- Instil in the minds of all people a conviction of the values of peace in such a way as to promote the creation of new lifestyles and living patterns.

This paints a very different picture to that being advocated by many school subject curricula. And, yet it is interesting to surmise how different it is from the intended goals of education in any country.

Science and technology education related to sustainable development. Equipping students with the knowledge, skills and values to participate in the key socio-scientific issues facing developing countries today (food scarcity, poverty alleviation, HIV/AIDS, peace building, global warming, cloning, embryonic stem cell use, toxic waste disposal, sustainable development, etc.) makes good sense in the compulsory years of education. To this end, three important criteria for change within science and technology education (and hence chemistry education) are put forward as – student relevance, practicality within the society, and civil commons values (Holbrook, 2009):

- *Relevance* implies the use of community resources and the incorporation of local issues and practices into the chemistry curriculum. The learning is intended to relate to the community, especially at a local level. The intention is that the learning is viewed by student as meaningful, timely, important, and useful.
- *Practicality* means activity-based learning (thinking and doing leading to action). The quality of the chemistry education is thus measured in terms of student actions, not from what the teacher is able to provide. This action relates to the competencies to be developed (for a democratic approach – the four competency areas).
- *Values* involve cultural and social issues, personal interdependence, and informed judgement, both from a holistic view of the world and from the local society perspective. It is heavily related to well-reasoned, socio-scientific decision making.

Assessment strategies and emphasis

Assessment and evaluation are central to educational reform initiatives all over the world (WNCP, 2006; see Chapter 2). Evaluation is more closely aligned with research and explores the effectiveness of the curriculum, the teaching or the assessment system. This is strongly promoted in developed countries, but far less so in emerging and developing countries. A major factor here is the cost of carrying out the monitoring or evaluation of systems. This is partly indicated by the lack of developing countries participating in international evaluative studies.

Assessing students is, however, very prevalent in developing countries and often this can be 'high stakes' (failure in any component means students drop out of the system). Nevertheless, there are two approaches seen as important to describe the ways learning is assessed, even for developing countries. One approach is the use of classroom-based assessment (sometimes called school-based assessment), conducted by the teacher in a formative, or more usually as a series of summative assessment measures. The other approach is a final summative performance on external (public) examinations, although both approaches can be utilised.

When not restricted to a single approach, such as solely written examinations, assessment activities can cover a wide variety of goals and roles, so much so that assessment carried out in the classroom situation can be regarded as an integral part of the teaching-learning process. In this regard, assessment practices in science education have undergone significant changes in recent decades and classroom assessment, whereby formative feedback to the teacher can guide further teaching as well as feedback to guide student progress, has become a major part of the agenda for improving student learning (Krugly-Smolskaa, 1990; Lewin, 2000). Alas, classroom assessment in developing countries is more likely to be a series of summative tests, further promoting the economic view of chemistry learning over the more democratic approach favouring a broad spectrum of chemistry education gains for all.

There remains, however, much potential for classroom assessment to introduce new techniques, encompassing oral and observation assessment as well as the marking of written formats (see Chapter 2). Such approaches mean rethinking teaching and curriculum coverage and making a fundamental shift in thinking about how and why assessment and teaching are integrally connected (WNCP, 2006). As put forward by Stiggins (1998), teachers will be expected to be far more assessment literate in the future, and, in fact, virtually every set of standards of teacher competence developed recently points to an expectation that teachers will need to be more competent in utilising a range of assessment strategies.

In general, approaches to classroom assessment have been described in recent literature as assessment *of* learning, assessment *for* learning, and assessment *as* learning (Hume & Coll, 2009; Earl, 2003). The latter two approaches shift the focus from a summative to a formative assessment practice and can be expected to play a key role in promoting chemistry learning within a democratic focus.

While assessment *of* learning – a summative approach, undertaken at the end of the topic, the section, or the course – is intended to certify learning and report about students' attainment and progress, this form of assessment tends to dominate most classroom assessment activities today, whereas formative assessment practices, although have gaining importance as alternative perspectives to traditional assessment in developed countries, are very much in their infancy in emerging and developing countries. Formative assessment can be described as a dynamic interaction between teaching and learning, designed to give feedback to teachers planning and guide learning through formal and informal means (Buck, Trauth-Nare, & Kaftan, 2010). However, in spite of the current attention paid to formative assessment strategies, recent research suggests two major issues need to be addressed:

– Teachers are still implementing a narrow interpretation of assessment as measuring learning, with classroom practices still dominated by summative assessment procedures and practices designed to assure students comply with external qualifications criteria (Hume & Coll, 2009), and
– In systems where student progress to reach accepted attainment levels are recognised, the authorities and government are concerned that teachers might show undue bias in assessing students. Thus, in trying to best promote their students, teachers award marks through classroom-based assessment (whether formative or summative) which are high and with little discrimination between students (low standard deviation). Governments thus become reluctant to allow classroom-based assessments to be included in the overall student assessment, especially where the assessment outcomes are 'high stakes.'

For the first issue, related to the summative assessment, the same gaps in teachers' education that affect teaching methods applied within classrooms also affect the assessment strategies. Teachers without training tend to reproduce traditional strategies of teaching and assessment. In this way, like any other country, teacher preparation within emerging countries must seek to better prepare teachers to successfully apply formative assessment and adjust instructional practice according to its outcomes. Also teachers need to be guided to operationalise formative assessment processes towards enhancing student progress.

One problem always mentioned by teachers related to assessment in developing countries is the number of students per class and per teacher. So the question is how to perform formative assessment in a class with fifty or even more students? In Chapter 7, one can note a range of alternatives in terms of collaborative learning that can also drive alternative assessment methods. Cooperative methods of learning, like the pairs-to-share method, or jigsaw classrooms can be implemented with big classes, as can the use of scenic interpretations, or role-play. But the activity has to be structured in such a way that the teacher has enough time to circulate between groups and observe students both in groups and individually, even where teachers make use of peer assessment techniques. Also, there are likely to be specific moments during such activities where students are in a bigger group. The assessment in this way can assess students within a group and provide teachers with more data about their students' progress in different situations – individually, small and also big groups.

In relation to the second issue, most countries use external examinations throughout the system for students at the secondary education level. Assessment of student learning outcomes can be used for making curricular decisions, allocating resources, and monitor teacher practices. However, the use of standardised tests or assessment data for decision making is not always consistently related to learning outcomes and is limited to those learning outcomes measurably under such conditions. In chemistry these are likely to be more related to cognitive learning than to problem solving and decision making in authentic situations. And unfortunately, assessment is often used to determine which students enter the next level of the educational system.

Inevitably, there is a very real danger in emerging and developing countries that the examination dictates the teaching curriculum that is followed by the teacher. The teacher is under pressure to teach to the examination. The examination assumes students to have covered specific content or topics, but has scant regard for other educational attributes, some of which have been pointed out as important previously (and put forward in earlier chapters such as those focusing on the need to promote scientific literacy, see Chapters 1 and 2). Until the external examination system requires that teaching and learning of chemistry is not the same as becoming a chemist and goes beyond testing the acquisition of content, plus conceptual understanding, but little else, there is little opportunity for the teacher to promote a democratic development approach to the teaching of chemistry more relevant for everyday life.

To illustrate this worry in a developing country, school based assessment, as classroom based assessment is known in Bangladesh, is practiced for students in grades 6-9. In this, teachers are required to assess across the school year in a range of learning attributes including behaviour. Unfortunately little accountability is currently being suggested and teachers have adopted a practice of giving marks at the end of the year in a summative fashion thus undermining the whole process. Marks for attitudes are closely correlated with those for conceptual development. The prevailing attitude is that unless the school marks are integrated into the public examination system, counting for a meaningful percentage of the total (maybe is 30% needs to be assigned), teachers will give little seriously attention to the school based assessment. But this is far from being the case as many educators and parents worry that the school-based marks will show bias and lead to a system that is inherently unfair. As Bangladesh is a country where student numbers are huge, statistical moderation processes are a possibility, but until there is expertise to handle such processes the situation reaches stalemate.

On the other hand, the contrasting situation in some states in Brazil, an emerging country, student results in official assessments systems are used as a way to achieve more investment for the corresponding school and also teacher's salaries are increased depending on these students' results. Also, the number of students that look for adult education in night courses in Brazil has increased. The explanation is that these courses are shorter and it is easier to be successful in obtaining the final certificate, necessary to apply for certain types of employment. So these adult courses are being attended by young students who should be in regular secondary schools.

Another example is related to what happens in Brazil where the entrance to the public universities is through an external examination at the end of secondary education. At this point it is relevant to clarify a general distinction between public and private schools in Brazil during elementary, what is fundamental and high school levels. The private schools have, in general a better reputation in terms of quality than public ones, even though a known exception occurs with federal technical schools, which are very well considered. The opposite happens at the university level, where the public institutions are considered of better quality than private ones. There is an entrance examination to access the best public universities at the end of high school and there are many preparation courses geared to these examinations. This provides a contradictory situation, students who access the public universities are, in general, the ones who can pay for private education during the fundamental and intermediate levels (Corio & Fernandez, 2010).

As mentioned earlier, official education documents in Brazil emphasise innovative strategies in teaching-learning, reflecting a student-centred approach. However, these approaches are followed in general by public schools but less by private secondary schools where the curriculum focus is guided by the university entrance examination. Thus, in general, students that are able to pass the public university entrance examination are the ones who studied at private schools, where the curriculum has followed, most commonly, an economic development type of approach. Students from public secondary schools, where the curriculum is more closely aligned to a democratic and cultural development approaches are less well prepared to pass in the examination which is focussed on content.

On the other hand, in the last decade, the federal university system in Brazil has expanded enormously and additional opportunities for students to further their studies have been created. In order to enter federal universities, another examination (the high school national examination) focusing on competences and skills rather than the content itself has been used. So the situation is changing a great deal and the number of students from public schools entering the public federal universities is increasing. But in spite of this change, lower income students are mostly to be found in the private universities and in general enrol in night courses.

From these examples one can recognise that assessment, in developing or emerging countries like Bangladesh or Brazil, plays an important role related to further education and hence better job opportunities. Also at times survival issues of students remaining in school are at the centre of the scene, where ethical aspects related to social injustice and economic disparities are brought inside classrooms and teachers are sometimes the ones responsible for making the final decision.

The external summative examination in chemistry, which is intended to determine the learning that has taken place, obviously must focus on the goals stipulated for the teaching of chemistry. It is insufficient to only focus on that which is easy to assess; the acquisition of knowledge, seeking explanations or applications as well as analytical and evaluation aspects of the subject matter of chemistry. In democratic and cultural development curriculum approaches, the assessment is expected to include coverage of learning associated with socio-scientific aspects that link the subject to learning geared towards problem solving skills, decision making, inquiry-based learning and the competencies associated with the transfer of knowledge, skill and values to new situations. On the other hand, a skills emphasis curriculum can be expected to include assessment strategies related to practical elements, although a school-based practical examination may be untenable in a developing country. This is illustrated in Bangladesh where a school-based practical examination in chemistry traditionally yields mean score of 90% or more, far higher than the mean score for a multiple-choice paper, or a paper based on written questions.

THE PRACTICE OF CHEMISTRY TEACHING

Teachers, in all countries, face constraints in the teaching of chemistry. Major problems linked to the teaching of chemistry in developing countries are often associated with:

– Poor professional development,
– Too few chemistry lessons for the students to gain sufficient useful chemistry learning,
– The issue of teaching to large class sizes,
– The poor provision of laboratory facilities and accompanying technical support, and
– The inadequate level and supply of apparatus and chemicals.

Poor professional development. This issue has been mentioned earlier and is obviously a major issue in developing countries, limiting a more enlightened teaching force able to focus the teaching in response to the student needs and hence take a relevant approach to enhancing student motivation for self-determination and to provide a meaningful challenge for all students. Possibilities to reflect on this issue are addressed in Chapter 10.

Too few chemistry lessons for the students to gain sufficient effective chemistry learning. This is a political issue and relates to the importance of teaching chemistry in the face of other educational demands, often the need to acquire strength in using an international language. Nevertheless, the limited time induces teachers to adopt more pragmatic teaching processes which enable students to take more responsibility for their own learning. In furtherance of the importance of student involvement it becomes more relevant in developing countries to select chemistry content related to the society. This enables teachers to place importance on aspects in the curriculum to which the students can relate and build on their prior experiences. Taking opportunities to interrelate the teaching to other subjects, for example, in promoting communication or presentation skills, is another approach from which the teaching of chemistry can benefit.

The need to teach to large classes. There is always the temptation to adopt a teacher centred approach and lecture to the students. Research has repeatedly shown this to be ineffective in promoting more than short term memory gains. It is a transmission mode and leads to student inactivity, diminished student concentration span and with the teaching proceeding at a pace which does not take into account student needs. Far more attractive for this situation is the use of cooperative learning (see Chapter 7). The organization of students into smaller groups can be expected to provide opportunities for the teacher to observe and interact with their students, something almost impossible in a teacher-centred approach.

Student centred teaching means opportunities are taken for students to work in small groups (3-5 students) where students learn from each other, cooperate collaboratively with each other determining and working on the appointed tasks and where the teacher takes on a facilitator role guiding the groups to greater and greater self-determination. For a really large class, where safety issues could also be a factor, student self-evaluation will also need to feature. Unfortunately the amount of time a teacher is expected to work with any one group will be small and group-group interactions can also be expected to be a strong classroom feature. A major teacher concern is that students are facing a meaningful and manageable challenge and are not inactive because the challenge (often through the choice of medium of instruction) is too great.

Interesting possibilities for tackling issues of large class sizes include encouraging students (perhaps from a higher class where reinforcement of the learning is supported) to assist teachers, and allowing for the best students in their class to support fellow students. Also, a further possibility includes dividing the whole class of students into smaller groups, and alternating these groups between different activities. This can relate to different activities in the same class (each group working on their own assignment) or even, if appropriate support is made possible, in different locations, i.e. while half of the students would stay in class (planning a physics investigation, for instance) the other half would be involved in undertaking a pre-planned practical activity so as to obtain the appropriate evidence to solve a scientific problem (in chemistry, for instance). This allows for the teacher to deal with fewer students at any time.

The poor provision of laboratories and lab technicians. While there are laboratories in a number of schools in developing countries, there is generally a lack of technical support to aid the setting up and organisation of a laboratory. The possibility for student teachers to assist chemistry teachers in establishing the laboratory as part of their training does exist, but this can only be considered as a temporary arrangement. An alternative approach, which can be considered where safety is not being compromised, is for students to take responsibility for the collection, setting up of apparatus, and cleaning up after the laboratory sessions. Such an approach is much easier if it is practiced, starting with very young students so that students have been taught, as part of their learning, how to be able to handle delicate apparatus and to obtain and use appropriate quantities of chemicals. Also, for this to be successful it obviously needs students to possess a strong sense of peer group responsibility for the safety of others, a key learning component for a democratic approach to the teaching of chemistry.

Figure 2. An example of a low-cost calorimeter

The inadequate level of apparatus and chemicals. In developing countries, low-cost techniques (e.g. Poppe, Markic, & Eilks, 2011) should be standard practice in chemistry lessons. That can mean adaptations are necessary in order to conduct meaningful experimentation with resources which are easily found. Inevitably this points towards home-made (by the teacher or perhaps, more exciting and a learning challenge, by the students) equipment which, for example, can be a calorimeter (a soft drink can or plastic cup in a beaker (Figure 2), a colorimeter (colour matching against a series of standards), or distillation equipment (an interesting challenge, especially in making it water-tight). Additional examples can be seen on the website of the International Council of Associations for Science Education (www.icaseonline.net/pub.html) or the collection of experiments of the project SALiS (www.salislab.org).

In addition, there are many curriculum materials on the internet which try to offer teachers ideas on how to do classical chemistry experiments with materials from everyday life (e.g. see the UNESCO database). These alternatives may combine the idea of micro-scale (small scale) kit approaches with the principle of low-cost experimental equipment e.g. where the traditional laboratory glassware (or micro-scale glassware) may be replaced by less expensive alternatives, often made of plastic. One such example is the project Student Active Learning in Science (SALiS) which offers a guide and collection of examples for low-cost equipment and experiments.

Figure 3. RADMASTE-Kit for water (Image: www.radmaste.org.za)

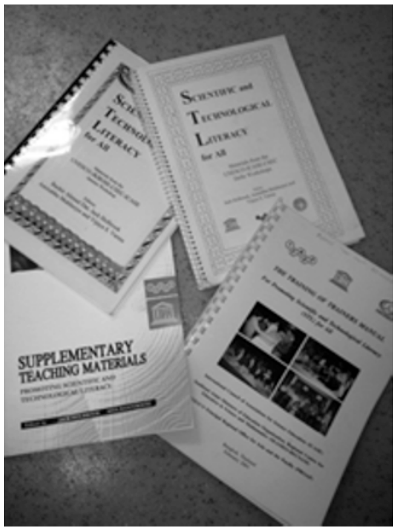

Figure 4. A selection of publications on www.icaseonline.net/pub.html

Another example of a microscale operation is the *RADMASTE kit*, distributed from South Africa and used in a number of countries. This kit is available in different versions, ranging from primary science, chemistry and biology and offers the potential for setting up experimental situations that would be difficult under normal circumstances. An illustration of a water kit is given in Figure 3 plus a picture of a collection of publications on experimental ideas taken from the ICASE website (Figure 4).

SUMMARY: KEY SENTENCES

- An important question, which all countries, but especially emerging and developing countries, need to face, is: Why teach chemistry? It is suggested there are four separate developmental components: (a) enhancing democratic development, (b) supporting economic development, (c) promoting skills development, and (d) the need for cultural development. All have a place in chemistry teaching, but a democratic emphasis is clearly more appropriate for all students irrespective of their future career plans.
- The educational focus for emerging/developing countries needs to be carefully considered at a political, as well as an educational level. The curriculum, teaching and assessment system for education, in general, needs to be oriented according to forward thinking and future national priorities.
- Assessment practices have the power to directly impact on the actual curriculum implemented by teachers in schools. An external examination system is notorious for dictating the teaching emphasis, often being at odds with the wider, intended curriculum.
- Student centred learning approaches are important within chemistry teaching. Specific pedagogies (cooperative learning) and laboratory techniques (e.g. micro-scale and low-cost-chemistry experiments) are available to promote student active learning in developing and emerging country environments.
- Even though there are a multitude of constraints to teaching chemistry in developing and emerging countries, chemistry needs to be promoted in a relevant and meaningful manner. This is important, firstly for the economic and environmental development of the country, secondly in terms of the role of chemistry teaching in discussing social issues and finally in terms of supporting evidence-based personal choices (e.g., food and health) all of which relate to the importance of chemistry.

ASK YOURSELF

1. Explain in which respect chemistry teaching in an emerging or developing country has to be considered different from the perspectives within a developed country.
2. Outline a justification for the special importance of a democratic emphasis for chemistry teaching in emerging or developing counties.
3. List the potential limitations a teacher of chemistry in an emerging or developing country might face in comparison to a teacher in developed countries.
4. Outline suitable pedagogies for teaching chemistry in emerging or developing countries.
5. Explain: What is meant by low-cost and microscale chemistry experiments?

HINTS FOR FURTHER READING

Risch, B. (2010). *Teaching chemistry around the world.* Berlin: Waxmann. This book analyses the approach to chemistry education in different countries from all over the world, and may be seen as a contribution to make the structure of chemistry teaching in numerous countries more transparent and to facilitate communication. The country studies presented in the book show that educational systems differ widely. Twenty five countries, including developed and developing countries, participated in the project.

Fensham, P. (2008). *Science education policy-making: 11 emerging issues*. Paris: UNESCO. This document was inspired by the 2007 World Conference on Science and Technology Education in Perth, Australia. The paper collates many comments on educational policy during the conference to promote and reform science education. The document was commissioned by the UNESCO.

Ware, S. A. (ed.). (1999). *Science and environment education views from developing countries*. Washington: World Bank. *www.eric.ed.gov/PDFS/ED456025.pdf*. This book is a collection of 16 chapters focusing on the development in science education in less developed environments from all over the world, e.g. Mexico, Costa Rica, Thailand, or Nigeria.

Malcolm, C. (2007). The value of science in African countries. In D. Corrigan, J. Dillon, & R. Gunstone (eds.), *The re-emergence of values in science education* (pp. 61-76). Rotterdam: Sense. This book chapter discusses in the case of African countries the specific embedding science education can have in the foreground of different cultures.

McKinley, E. (2007). Postcolonialism, indigenous students, and science education. In S. K. Abell & N. G. Lederman (eds.), *Handbook of research in science education* (pp. 199-226). Mahwah: Lawrence Erlbaum. The chapter discusses specific science education research for indigenous students and sets up an agenda for helping them in promoting their interests.

RESOURCES FROM THE INTERNET

ICASE: www.icaseonline.net. A range of resources for science teachers from equipment design (often in conjunction with UNESCO), experimental ideas and teaching resources. The website also includes an open access, online journal – *Science Education International* – and a monthly newsletter.

Microscience www.microsci.org.za. The UNESCO-associated centre for microscience experiments in South Africa offers hints for low-cost-experiments. Low-cost-kits can be ordered and manuals can be obtained.

Student Active Learning in Science (SALiS): www.salislab.org. This EU-TEMPUS project offers a lab manual for low-cost- and microscale-experiments.

A database of low-cost experiments is offered with examples in different languages.

UNESCO: www.unesco.org/new/en/unesco/resources/publications/unesdoc-database/. A range of resources can be found, among them teaching materials, guides, and political statements on the development of science education worldwide.

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CONTRIBUTORS

Dr. Ian Abrahams is a senior lecturer in science education at the University of York (UK). His current research interests relate to practical work, teachers' attitudes to practical work, and science teachers' continuous professional development (CPD). He recently led the evaluation of the national 'Getting Practical - Improving Practical Work in Science'-project and is currently leading an evaluation of a large-scale CPD programme for primary science coordinators.

Dr. Ron Blonder worked as the chemistry coordinator and the director of the Belmonte Science Laboratories centre for high school students at the Hebrew University of Jerusalem and is now a senior researcher in chemistry education at the Weizmann Institute of Science (Israel). She is engaged in research in science education focusing on chemistry and nanotechnology education and professional development of chemistry teachers.

Prof. Dr. Claus Bolte worked as high school teacher in chemistry and physical education. Since 2004 he is professor and head of the department of chemistry education at the Freie University Berlin (Germany). His research focuses on the investigation of student-teacher-communication and interactions, motivational learning environment research and STS-based science education. Further interests encompass on the question of how to promote students' ability on critical thinking and proper judgement, the correlation of students' language skills and science learning, and on how to promote language competencies of migrant and non-native speaking students in formal and informal science learning environments.

Dr. Joanne Broggy is a lecturer in science education at the University of Limerick (Ireland). Her research interests include effective teaching methodologies to engage students in conceptual understanding of science by inquiry methods, problem-based and research-based learning. She is also interested in effective teacher education, assessing scientific language and sustaining science from primary level to university. She also works as an in-service science teacher trainer and projects officer in the Irish National Centre for Excellence in Mathematics and Science Teaching and Learning (NCE-MSTL).

Dr. Peter Childs started his career in teaching chemistry at Makerere University (Uganda), where he began to support chemistry teachers. From 1978 was involved both in teaching chemistry and chemistry education at the University of Limerick (Ireland). He runs workshops and in-service courses, is producing a chemistry teacher magazine, and initiated the annual ChemEd-Ireland conferences. He also conducted chemical education research into the improvement of the teaching and learning of chemistry at second and third level. Today, he is an associate director the Irish National Centre for Excellence in Mathematics and Science Teaching and Learning (NCE-MSTL).

Prof. Dr. Richard K. Coll worked as a lecturer in chemistry in the Pacific and Caribbean before he was appointed a professor of cooperative education at the University of Waikato (New Zealand). His research is in the area of science education and cooperative and work-integrated education. He is currently Pro Vice-Chancellor for teaching and learning at the University of Waikato.

Prof. Dr. Onno De Jong was a teacher in several secondary schools in the Netherlands, thereafter became chemistry educator and researcher at Utrecht University (The Netherlands), and finally was professor of chemistry education at Karlstad University (Sweden). He also worked as invited scholar at universities in South Africa, Malaysia, Australia and Taiwan. He has ongoing interest in bridging the gap between 'Theory' (given in chemistry teacher courses) and 'Practice' (in chemistry classrooms).

Prof. Dr. Yehudit Judy Dori is a professor in science education and dean of continuing education and external studies at the Technion – Israel Institute of Technology, Haifa (Israel). For many years, she was also a visiting scholar and visiting professor at the Center for Educational Computing Initiatives at Massachusetts Institute of Technology, Cambridge (USA). Her research interests encompass learning by information and communication technologies, scientific visualizations, higher order thinking and metacognitive skills, educational assessment at high school and university levels, and distance education.

Prof. Dr. Ingo Eilks was a high school teacher for chemistry and mathematics and then became appointed a professor for chemistry education at the University of Bremen (Germany). His research interests encompass curriculum development in the field of societal-oriented science education, education for sustainable development, cooperative learning in science, teachers' beliefs and knowledge, as well as action research in science education.

Prof. Dr. Carmen Fernandez used to be a chemistry teacher, working for different secondary schools, before becoming an assistant professor of chemistry education at the University of São Paulo (Brazil). Her research interests include chemistry teacher education both pre- and in-service, teachers' knowledge, pedagogical content knowledge and professional development.

Prof. Dr. John K. Gilbert is professor emeritus of The University of Reading, and now visiting professor of science education at King's College London (UK). His initial research interest in students' alternative conceptions evolved into a focus on models and modelling, then into visualization, and currently into the implications of all these for informal learning and for teacher education.

Prof. Dr. Avi Hofstein was the head of the chemistry education group at the Department of Science Teaching of the Weizmann Institute of Science (Israel). His research focus all facets of the curricular process in chemistry namely development, implementation, research, and evaluation. He has conducted research e.g. in learning environment, affective issues, learning difficulties and misconceptions in science learning, professional development, and laboratory work. In recent years, he has been involved in the development of leadership amongst chemistry teachers in Israel in order to promote reform in the way chemistry is taught in high schools.

Prof. Dr. **Jack Holbrook** taught chemistry in different secondary schools before moving into teacher education, first in the UK, then overseas, most notable Tanzania and Hong Kong. Today he is a visiting professor of science education in the University of Tartu (Estonia) and an international consultant in the field of education working mainly in Africa and Asia. His main research interests lie in the philosophy of science education as well as assessment strategies, motivational strategies considered from the student perspective, and the relevance of science education in promoting 21st century skills.

Dr. Mira Kipnis has twenty five years of experience in teaching chemistry in high schools in Israel. She also worked as a researcher at the chemistry education group at the Weizmann Institute of Science (Israel). Her research deals with the learning processes of students in the inquiry chemistry laboratory. She also is involved in several programs of continuous professional development for chemistry teachers.

Prof. Dr. Reuven Lazarowitz was a high school biology teacher and later became a professor in science education at the Technion – Israel Institute of Technology, Haifa (Israel). He was a visiting professor in Universities in USA, UK and Australia. His research interests are on cognitive and affective outcomes of high school students studying science by inquiry methods within computer assisted learning environments, cooperative and individualized learning, and teacher education. He worked in the development national curricula and contributed curriculum development in the field of STS-oriented science education.

Dr. Rachel Mamlok-Naaman worked as a chemistry high school teacher and later became researcher and coordinator of the chemistry education group at the Weizmann Institute of Science (Israel). She is engaged in development, implementation, and evaluation of new curricular materials, and research on students' perceptions of chemistry concepts. She also focuses on scientific and technological literacy, cognitive aspects of students' learning, assessment, teachers' professional development, and action research.

Dr. Silvija Markic worked as a high school teacher in chemistry and mathematics before she became a senior researcher in chemistry education at the University of Bremen (Germany). Her research interests focus curriculum development in chemistry and science education, language and the learning of science, linguistic heterogeneity and cultural diversity in science education, teachers' beliefs and knowledge base, and action research in science education.

Dr. John Oversby was a high school teacher in all sciences in Ghana and the UK for 22 years. Later he started working in science teacher education at The University of Reading (UK). His research interests are in chemical education at all levels, teacher subject knowledge, teacher education, modelling, and the pedagogy of teaching controversial societal issues in science education. Although now formally retired, he remains active, working with voluntary teacher researcher groups.

Prof. Dr. Albert Pilot is professor emeritus of curriculum development and also professor emeritus of chemistry education at Utrecht University (The Netherlands). His research focuses on context-based chemistry education and professional development of science teachers. In recent years this involved the design and development of a new chemistry curriculum for the secondary school in the Netherlands. Professional development of teachers was a major component in this innovation project, planned for many years and involving all teachers in the chemistry domain.

Dr. Gjalt T. Prins worked as a high school teacher in chemistry and is now a researcher in science education at Utrecht University (The Netherlands). His research is on the use of authentic practice based curriculum units to foster students' higher-order thinking skills, like causal reasoning and modelling. He also is interested in teaching about communication skills, competencies of science teachers and innovation and dissemination in the field of science education.

Prof. Dr. Bernd Ralle was a teacher for chemistry and biology in high school for ten years before he became appointed a professor of chemistry education first at the University of Osnabrück, thereafter at the Dortmund University of Technology (Germany). His research interests encompass curriculum development, context-based chemistry education, action research, and the role of language in the learning of science.

Prof. Dr. Franz Rauch was a science teacher for several years and is now head of the Institute of Instructional and School Development (IUS) at the Alpen-Adria University Klagenfurt (Austria). His areas of research are environmental education, education for sustainable development, science education, networking of teachers, school development, continuing education for teachers, and action research.

Prof. Dr. Susan Rodrigues is professor in science education at Northumbria University (UK). She conducts research into the teaching and learning of science. Her work is making a contribution both to innovative practice and to theory as her research explores issues such as the language of science, teacher professional development, and how ICT can be used to transform teaching, learning and assessment in science

Prof. Dr. Sascha Schanze is professor of chemistry education at the Leibniz Universität Hannover (Germany). His research focuses collaboration using computer-supported learning environments, collaborative inquiry learning in science, and the use of cognitive tools as a reflective tool in learning processes, like computer-based concept mapping.

Dr. Yael Shwartz taught high-school chemistry for ten years and is now a senior scientist in chemistry education at the Weizmann Institute of Science (Israel). She has been involved in context- and inquiry-based curriculum development, implementation and assessment both in Israel and the US. She has a rich experience in designing and implementing various models of teacher's professional development, including facilitating on-line programs. Her research interest is focused on chemical literacy, the value for teaching chemistry to all, coherence and knowledge integration, integrating thinking skills into chemistry education, and student' motivation to study chemistry.

Prof. Dr. Sabine Streller is a professor of chemistry and biology education at the RWTH Aachen (Germany). Her research interests are in students' interests in science and the development of interests, students' perceptions of science concepts, and approaches to enhance the professionalization of in-service teachers. She has several years of experience in pre- and in-service science teacher training, as well as in developing and conducting out-of-school science courses for children.

Prof. Dr. David F. Treagust is professor of science education at Curtin University, Perth (Australia). His research interests are related to understanding students' ideas about science concepts and the roles of multiple representations, and how these ideas and roles contribute to conceptual change and can be used to enhance the design of curricula and teachers' classroom practice.

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