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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,

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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 submicroscopic 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.)

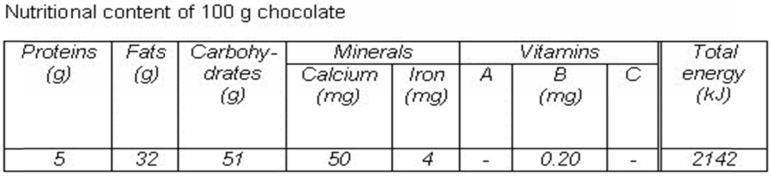
The PISA content dimension includes life systems, physical systems, earth and space systems, and technology systems. Knowledge in chemistry is not assessed separately. However, it is possible to use a similar framework to assess students' chemical literacy by giving students a short adapted scientific 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).

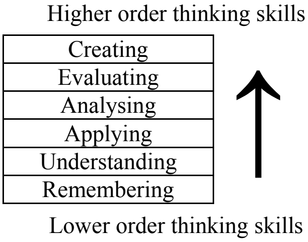


Figure 2. Bloom's revised taxonomy

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	Demonstrate the importance of chemical knowledge in finding treatments for medical problems. To demonstrate the applicative nature of chemical knowledge
	Affective aspects	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	Chemistry investigates the dynamics of processes and reactions
	Higher-order thinking skills	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/ submicroscopic, 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/submicroscopic, 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	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
	Higher-order thinking skills	Chemists use a specific language
Enzymes	Chemical ideas	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
	Chemistry in context	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°C, while the molar mass of patulin is 154 g/mol, with melting temperature of 110°C. Describe the melting processes of NaI and patulin. Explain the difference between these two processes.

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

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

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

Use alternative assessments in chemistry lessons

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

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

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

Sodium chloride, NaCl, exists as a molecule.

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.

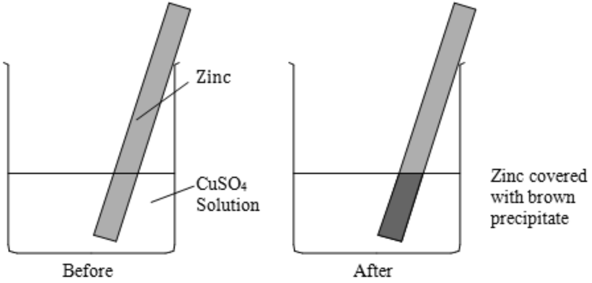
Figure 4. Example of a two-tier multiple choice item

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?

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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

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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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