The use of scientific literacy taxonomy for assessing the development of chemical literacy among high-school students

Yael Shwartz*[†], Ruth Ben-Zvi and Avi Hofstein

The Department of Science Teaching, The Weizmann Institute of Science, Rehovot, 76100, Israel
e-mail: yaels@umich.edu

Received 26 April 2006, accepted 1 August 2006

Abstract: This study investigated the attainment of chemical literacy among 10^{th}-12^{th} grade chemistry students in Israel. Based on existing theoretical frameworks, assessment tools were developed, which measured students' ability to: a) recognize chemical concepts as such (nominal literacy); b) define some key-concepts (functional literacy); c) use their understanding of chemical concepts to explain phenomena (conceptual literacy); and d) use their knowledge in chemistry to read a short article, or analyze information provided in commercial ads or internet resources (multi-dimensional literacy). It was found that students improve their nominal and functional literacy; however, higher levels of chemical literacy, as defined within these frameworks, are only partly met. The findings can be helpful in the process of designing new curricula, and emphasizing certain instructional strategies in order to foster chemical literacy. [*Chem. Educ. Res. Pract.,* 2006, **7** (4), 203-225]

Key words: scientific literacy, chemical literacy, high-school chemistry

Introduction

In science education we operate in an era in which achieving scientific literacy for all students is one of the main goals (NRC, 1996). The National Research Council (NRC) of the USA, and the American Association for the Advancement of Science published new standards and benchmarks regarding the content, pedagogy, and assessment of chemical literacy (AAAS, 1993; NRC, 1996). Scientific literacy is a broad term that incorporates scientific ideas and concepts within and across various scientific disciplines, as well as scientific practices. In order to understand the various components of scientific literacy, there is a need to investigate the unique components of literacy in the various scientific subjects. Several attempts were made to identify the various dimensions of biological literacy (BSCS, 1993). Efforts to establish a theoretical definition for chemical literacy were conducted by Yfrach (1999), Holman (2002), and more recently by Atkins (2005), and by Shwartz, Ben-Zvi and Hofstein (2005). The last definition was used as a framework for the current study, as will be described in the following sections.

Assessment of scientific literacy

Assessment is an important component of studying and learning. It is also important when the achievement of scientific literacy is the main learning goal. Two of the most comprehensive survey programs aimed at assessing scientific literacy are: The Program for

[†]Center for Curriculum Materials in Science University of Michigan School of Education, Ann Arbor, MI, USA

International Student Assessment (PISA) of the Organization for Economic Co-operation and Development (OECD, PISA, 2005), and Trends in Mathematics and Science Studies (TIMSS) (NCES, 2006). Whereas TIMSS focuses mainly on the recall of content taught, PISA tends to focus on 'practical knowledge in action', namely recognizing questions as scientific, identifying relevant evidence, critically evaluating conclusions, and communicating scientific ideas (Fensham and Harlen 1999; Backer, 2001; Harlen 2001; OECD/PISA, 2005).

In addition, different philosophies, different theoretical frameworks, as well as different research agenda led the development of various research tools that try to assess a distinct aspect of scientific literacy, which usually focuses on one of the following:

- Measuring recall resulting from school science knowledge. Content knowledge is usually considered to be important to scientific literacy, and therefore, it is the aspect mostly assessed by teachers and science educators (Laugksch and Spargo, 1996a, 1996b).
- Measuring the ability to apply scientific principles in non-academic contexts. The main characteristics of such tools are designing authentic tasks (such as reading the information on a gas or electricity bill), and evaluating performance capabilities. In this approach the recall of scientific content knowledge is secondary, and the assessment is focused on the manifested skills (Champagne and Newell, 1992; Zuzovsky, 1997; Champagne and Kouba, 1998; Fensham and Harlen, 1999).
- Measuring literacy abilities in a scientific context, namely, to evaluate the ability of individuals to read, write, reason, and ask for further information (Wandersee, 1988; Champagne, 1997; Phillips and Norris, 1999; Duschl and Osborne, 2002; Norris and Philips, 2003; Simon et al., 2006). Some examples of this approach assess the ability to use media reports of scientific research (Norris and Philips, 1994, 2003; Champagne, 1997; Korpan et al., 1997).
- Measuring students' understanding of the nature of science (NOS), and students' understanding of science and attitudes toward Science-Technology-Society (STS) topics. For example, The Views on Science-Technology-Society (VOSTS) instrument developed and validated by Aikenhead and Ryan (1992).

Assessment of scientific literacy – theoretical perspective

In order to assess any aspect of scientific literacy, some theoretical issues need to be addressed: the first is the understanding that being scientifically literate is not a 'yes or no' situation. There are various levels and expressions of scientific literacy. For example, Shen (1975), Pella (1976), Scribner (1986) and Shamos, (1995) all suggested similar levels. The lowest level is often called *practical or functional literacy* and refers to the ability of a person to function normally in their daily life, as a consumer of scientific and technological products. It deals with basic human needs such as food, health, and shelter. Higher levels of literacy, such as *civic literacy* (or literacy as power), refer to the ability of a person to participate wisely in a social debate concerning scientific and technologically related issues. *Cultural or ideal literacy* includes an appreciation of the scientific endeavor, and the perception of science as a major intellectual activity. Shamos (1989) also suggested a *'passive to active'* scale, which differentiates recall of knowledge and memorizing from communicating and using scientific ideas.

Bybee (1997) and the BSCS (1993) suggested a comprehensive theoretical scale that is more suitable for the assessment of scientific literacy during science studies at school, since its hierarchy can be easily transferred to instructional purposes. This scale was used as one of the theoretical frameworks for the current study. The scale suggests the following levels of scientific literacy:

Scientific illiteracy: Students who cannot relate to, or respond to a reasonable question about science. They do not have the vocabulary, concepts, contexts, or cognitive capacity to identify the question as scientific.

Nominal scientific literacy. Students recognize a concept as related to science, but the level of understanding clearly indicates misconceptions.

Functional scientific literacy. Students can describe a concept correctly, but have a limited understanding of it.

Conceptual scientific literacy. Students develop some understanding of the major conceptual schemes of a discipline and relate those schemes to their general understanding of science. Procedural abilities and understanding of the processes of scientific inquiry and technological design are also included in this level of literacy.

Multidimensional scientific literacy. This perspective of scientific literacy incorporates an understanding of science that extends beyond the concepts of scientific disciplines and procedures of scientific investigation. It includes philosophical, historical, and social dimensions of science and technology. Here students develop some understanding and appreciation of science and technology regarding its relationship to their daily lives. More specifically, they begin to make connections within scientific disciplines, and between science, technology, and the larger issues challenging society.

Bybee (1997) refers to this framework as:

"A unique perspective that gives direction to those responsible for curriculum, assessment, research, professional development, and teaching science to a broad range of students" (p.86).

It is also important to note, that Bybee (1997) is aware of the fact that achieving multidimensional scientific literacy in all scientific domains is probably impossible, or a lifetime task, and may not be attainable at all. One can attain a high level of literacy, referring to a very specific topic (even without becoming an expert in terms of career, for example: some people who build airplane models as a hobby may achieve a deep understanding of aviation physics), but a lower level in other topics such as molecular genetics.

The taxonomy of scientific literacy levels does not suggest a teaching sequence, but rather a horizontal view as well as vertical development. Developing functional literacy, by enlarging students' vocabulary, should be done in a way that will also increase students' conceptual literacy by understanding the connections between concepts and the main ideas underlying the details. The challenge for developers of learning materials is to recognize and enhance all levels of literacy with respect to students' personal development and interests.

The second issue to be addressed when assessing scientific literacy, especially of young students, is the understanding that attainment of scientific literacy is considered to be a life-long process (Solomon and Thomas, 1999). In this context, the National Research Council (1996) in the USA wrote that:

"Scientific literacy has different degrees and forms; it expands and deepens over a lifetime, not just during the years in school. But the attitudes and values established toward science in the early years will shape a person's development of scientific literacy as an adult". (p. 22)

It is clear, that assessing scientific literacy during school years does not determine the final level of literacy a person will attain. Its purpose is only to measure the effectiveness of science studies in establishing attitudes, values, basic skills, knowledge and understanding of science. Thus, assessing scientific literacy during the students' years at school indicates whether the 'seeds of literacy' have found their place in the students' mind, nothing more.

Theoretical frameworks for the current study

The current study was designed in light of two theoretical frameworks. The first is the various levels for scientific literacy as suggested by Bybee (1997) and the BSCS (1993), as described in the previous section. The second theoretical framework provides the unique aspects of chemical literacy (Shwartz, 2004, Shwartz et al., 2005). A detailed definition for chemical literacy was developed, aiming at obtaining a wide consensus among scientists (chemists), educators, and high-school chemistry teachers. The process of development consisted of the following stages:

- Interviewing chemists and science teaching researchers. The interviews provided a variety of ideas that were used as triggers for further deliberation.
- Conducting a year-long professional development program, whereby chemistry high-school teachers discussed and reflected on various issues regarding 'scientific literacy', 'chemical literacy', and chemistry teaching (Shwartz et al., 2005). The teachers' view provided a sense of what a practical and working definition would look like, in contrast to an ideal definition of a literate person, which only few will actually achieve.
- Testing the extent of agreement concerning the content of the definition that resulted from the previous stages (Shwartz et al., 2006).

Table 1. Chemical literacy – an overview.

1. Scientific and chemical content knowledge
A chemically literate person understands the following ideas:
1a. ***General scientific ideas***
• Chemistry is an experimental discipline. Chemists conduct scientific inquiries, make generalizations, 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.
1b. ***Characteristics of chemistry (Key ideas)***
• Chemistry tries to explain macroscopic phenomena in terms of the molecular structure of matter.
• 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 processes of living systems.
• Chemists use a specific language. A literate person does not have to use this language, but should appreciate its contribution to the development of the discipline.
2. Chemistry in context
A chemically literate person is able to:
• Acknowledge the importance of chemical knowledge in explaining everyday phenomena.
• Use his/her understanding of chemistry in his/her daily life, as a consumer of new products and technologies, in decision-making, and in participating in a social debate regarding chemistry-related issues.
• Understand the relations between innovations in chemistry and sociological processes.
3. Higher-order learning skills
A chemically literate person is able to raise a question, look for information and relate to it, when needed. He/she can analyze the loss/benefit in any debate. (A list of skills and the appropriate chemical context is given in the full document of defining 'chemical literacy'.)
4. Affective aspects
A chemically literate person has an 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 programs).

As a result, the definition of chemical literacy consists of four domains, which are outlined in Table 1. The detailed definition states what every high-school graduate is expected to know about each of the key ideas, and be able to do with that knowledge. It also distinguishes between the knowledge and the skills of those who chose to major in science, and those who did not (Shwartz, 2004). It is important to note, that although science educators and high-school teachers were involved in the process of defining chemical literacy, the definition is not based on, or related to the current chemistry curriculum in Israel. The developers tried to construct a general definition, and in order to do so, addressed the views of scientists and chemists, who are not familiar with the current curriculum. The participating teachers also had to interview people whose profession requires chemical knowledge (e.g. a dietician, a physician, a hairdresser, and an electrician), regarding their views of the required chemical literacy for the public.

The study

As part of reform efforts in Israel, a committee nominated by The Ministry of Education and Science (1992) 'Tomorrow 98', recommended that all high-school students (aged 15 years and older) should learn science. In their first year of high school (10th grade) all students must study three basic courses: physics, biology, and chemistry (3 periods per week per subject), or eight periods a week of an interdisciplinary 'science for all' program. In practice, the latter option is not available in most high schools. Therefore most students (about 80%) who take the basic disciplinary courses do *not* continue with their study of chemistry to the advanced course (11^{th}-12^{th} grades). This situation makes the basic courses very important in terms of scientific literacy of all students.

Objectives of the study

The goal of the study was to provide an insight into the manifestation of various aspects of '*chemical literacy*' among high-school students at two levels of chemistry studies: the basic level, which is aimed at providing some scientific background to all high-school students, and the advanced level, which is intended for those students who opted to specialize in chemistry as their major subject in high-school.

More specifically, the research questions of the study were:

1. How does the basic chemistry course (10^{th} grade) contribute to the various levels of 'chemical *literacy*'?
2. How does the advanced chemistry course (11-12^{th} grade) contribute to the various levels of 'chemical literacy'?

The study was based on two theoretical frameworks: The definition of 'chemical literacy' (Shwartz, 2004; Shwartz et al., 2005), and the scale of levels of scientific literacy developed by BSCS (1993) and Bybee (1997), described in the previous section. These frameworks can be used to assess the attainment of the various components of chemical literacy. The findings can also affect some aspects of chemistry teaching, and whether different aspects should be emphasized. For example, it is possible that chemistry teaching emphasizes functional literacy (the ability to define concepts correctly), but not structural literacy (connecting these concepts into a coherent picture). It is important to note that although affective aspects are considered to be part of both science and chemical literacy and the measurement of attitudes toward chemistry took place, they will not be reported within the current study. In this study we chose to focus mainly on the cognitive aspects of chemical literacy.

Table 2. Distribution of the student population.

Purpose of data collection	N Schools	N Classes	N Students	Grade
Pilot study	2	4	131	10^{th} grade
Assessment of nominal, functional, and conceptual levels of '*chemical literacy*'	7	14	423	10th grade
	7	9	161	11th grade
	5	9	168	12th grade
Assessment of the ability to read and relate to an article regarding chemical issues	1	1	22	10th grade
	2	2	40	11th grade
	2	2	42	12th grade
In-depth interviews			18	10th grade
			3	12th grade

Methodology

Research sample

The students involved in this study were high-school students who studied chemistry at the basic level (10^{th} grade) and advanced level ($11\text{-}12^{th}$ grade), totaling about 1000 individuals. The distribution of student population is presented in Table 2.

The development of assessment tools

Since chemical literacy is a multi-dimensional and complex term, it is difficult to assess all its aspects and components. Therefore, based on the theoretical frameworks, a series of assessment tools was developed. For each level of literacy a specific aspect was chosen and assessed by various tools.

Questionnaire 1: *'Identifying and defining chemical concepts'*

This was aimed at assessing the *nominal* and *functional* levels of chemical literacy. The questionnaire consisted of a list of concepts such as: atom, electron, and ozone. The students were asked to rate the level of acquaintance with each concept on a Likert-type scale (1-3) that varied from "*Don't know the concept at all*" to "*Understand the meaning of it*". They also had to rate their desire to hear more about each concept on a 1-3 scale varying from "*Not interested at all*" to "*Very interested*".

Table 3.Categorization of chemical concepts.

Category	Items:	α Cronbach reliability coefficient
General scientific concepts	Conservation law, temperature, model, conclusion, fact, scientific theory.	0.68
Structure: sub-micro concepts	Atom, isotope, electron, ion, molecule, chemical bond.	0.82
Materials: general types of substances	Acid, base, fatty acid, protein, element, mineral, metal, polymers, compound, solution.	0.78
Materials: specific substances	Ozone, air, crude oil, carbon, steel.	0.70
Concepts relating to chemical reaction	Chemical reaction, reaction rate, electrolysis, combustion	0.71

Content validation: The concepts included in the questionnaire needed to reflect the main ideas in the 'chemical literacy' definition. Therefore, five members of the chemistry group validated the alignment of concepts to the main ideas. The concepts were also grouped into more general content-related categories, as detailed in Table 3. Only concepts of which at least 4 out of 5 judges agreed to their inclusion in a specific category were included. α-Cronbach reliability coefficient for all items is 0.93. In the second part of the questionnaire the students had to explain in their own words the following six concepts: molecule, chemical reaction, chemical bonding, acid, ozone, and temperature. The first three concepts represent essential chemical concepts (core concepts) and the last three were considered more daily and familiar concepts.

The students' explanations were categorized as correct, partially correct, and wrong. The categorization also distinguished between explanations that used macroscopic language and those who used molecular terms. Examples for each of the categories will be provided in the results section.

Questionnaire 2: *'Chemical explanations of daily phenomena'*

In this questionnaire the students' ability to refer to chemical explanations regarding a specific phenomenon was assessed. The development of this instrument consisted of the following steps:

1. Familiar chemical phenomena were chosen as the basis of this questionnaire, for example, a burning candle, a rusty nail, mixing water and oil.
2. Group interviews with eighteen students (2-6 students in each group), at the end of 10^{th} grade chemistry studies. The students were asked to suggest explanations for the phenomena and to discuss their suggestions. These discussions were audio-taped, and detailed transcripts were obtained.
3. Students' responses during the oral interview served as the basis for composing questionnaire 2, which was designed to assess the students' ability to explain chemical phenomena. The analysis of the transcripts provided correct and wrong explanations of each phenomenon. These answers were used as items in the questionnaire. This procedure increased the content validity of the questionnaire.

As a result of the development process described above 11 phenomena were chosen for the final questionnaire. Almost all the items had a contextual flavor, namely relevance to the students' daily experience. The inclusion of 11 different phenomena in the assessment tool seemed important as it could increase the generalization of the resulting data. In order to avoid students' tiredness and negative reactions toward a tedious questionnaire, and to increase the usability of the questionnaire, the 11 phenomena were divided into two different versions: one consisted of 5, and the second of 6 different phenomena; each phenomenon is followed by 5-7 sentences related to it. In each class 50% of the students answered each version randomly.

The internal reliability of every version was obtained by internal correlation (split half procedure): $\alpha_A = 0.75$; $\alpha_B = 0.80$. Also, a *t* test procedure ensured that there was no significant difference between the mean score in the different versions (Version A: M= 0.38, SD= 0.16; version B: M= 0.38, SD= 0.15). These results ensured that the level of items in each version and the total level of both versions were similar.

Students answering the questionnaire were asked to refer to few sentences relating to each phenomenon and determine whether a sentence is correct or not. They could also choose the possibility *"I do not know"*. Following is an example of an item in questionnaire 2:

"When a bottle of perfume is left open in a room - after several minutes the smell of the perfume fills the room. Following are several statements pertaining to this phenomenon. You need to decide whether the statement is correct or wrong. You can also choose the 'I do not know' option.

	Statements:	Correct statement	Wrong statement	I do not know
a.	Some of the perfume molecules leave the fluid and change into the gaseous state			
b.	Transition to the gaseous state will take place only if the boiling point of the perfume is lower than the temperature of the room			
c.	The perfume molecules spread throughout the room through collisions with other molecules in the air			
d.	The higher the temperature in the room, the faster will be the evaporation			
e.	A weak chemical bond forms between the perfume molecules and special receptors found in our noses			
f.	The bonding between the perfume molecules and the smell receptors in the nose is not a chemical bond but rather a biological bond			

Questionnaire 3: *'Critical reading of a short unknown paragraph'*

This questionnaire aimed at assessing the students' ability to analyze a paragraph, involving chemical information. This aspect is considered to be part of conceptual and multi-dimensional chemical literacy. To assess the manifestation of high-order cognitive skills (analysis, synthesis and interpretation of information) in a chemical context, we developed three short paragraphs: 'Green chemistry', which presented the role of chemistry in diminishing the problems of pollution and waste; 'Mankind and materials through history', which reviews the use and production of materials by mankind as a function of a growing understanding of the structure of matter, starting with the Stone Age and Iron Age, and ending with nano-technology as the next scientific horizon. The last paragraph deals with health issues as presented in advertisements. It consists of two citations from the media: one discusses the potential hazard of excessive salt consumption, and the other presents an advertisement of a natural herbal compound, helping people to reduce weight. Four members of the chemistry group revised the paragraphs, and agreed that high-school students should understand them and be able to answer the associated questions. The paragraphs were followed by open-ended questions, which can be divided into four categories:

1. Understanding the information included in the paragraph (reading comprehension);
2. Relating to former chemical knowledge;
3. Decision-making or reasoning;
4. Asking further questions.

Each student had to refer to one paragraph. All three paragraphs were administered in each class randomly.

Table 4 summarizes the tools used for assessing different levels of *chemical literacy*.

Table 4: Assessment of chemical literacy.

Level of literacy	The Chemical literacy domain	Specific aspect (ability)	Instrument
Nominal literacy	Content	Acquaintance with chemical concepts	Likert-type scale
Functional literacy	Content	Ability to define/explain a chemical concept	Open-ended questionnaire
Conceptual literacy	Content and Context	Ability to refer to chemical explanations of daily phenomena	Multiple choice Questionnaire
Multi-dimensional literacy	Context + Skills	Ability to refer to a written paragraph	Open-ended questionnaire

Data collection

The contribution of the basic chemistry course to students' '*chemical literacy*' was measured by a pre-post comparison. In order to determine the continuous contribution of the advanced course to students' '*chemical literacy*' two points in time were chosen: the middle of the advanced course and the end of the advanced course.

Most students (N~750 students) answered questionnaires no. 1 and 2. Only 5 classes (N=104 students) were chosen for the reading comprehension questionnaire (questionnaire 3). This is because this kind of task is time consuming, and presenting it to the classes that answered all the other questionnaires was not possible. The classes that answered the reading comprehension questionnaire represented a typical sample of the research population. However, since it is a different sample in size and identity - the results of this part of the study will be presented in a separate section.

Data analysis and interpretation

The analysis of students' questionnaires consisted of two types of comparisons:

1. Comparing the results of students at the beginning of the basic course (10th grade) and the end of it, in order to assess the contribution of the basic course to different levels of '*chemical literacy*' (*t* test procedure). The pre- and post-tests were administered in the same classes.
2. Analysis of Variance statistic (ANOVA) was used to compare the contribution of each of the grades, namely 10th, 11th, and 12th grades, to '*chemical literacy*' and to enable a continuous overview of high-school chemistry at all levels. This procedure was followed by Duncan's multiple range test (Winer, 1971), for the cases where ANOVA revealed a significant difference.

Analyzing student's responses to written paragraphs

We categorized students' answers, according to the following 1-3 scale:

1. Wrong answers and explanations that reveal no understanding or irrelevant reasoning.
2. Partially correct: contains evidence of some understanding, and a limited ability to reason.
3. Correct answers: demonstrating reasoning ability and understanding.

In addition, a two-way analysis of variance (ANOVA) was conducted in order to reveal whether there were significant differences between the paragraphs themselves.

Results

The students' achievements in each of the chemical literacy levels were interpreted in light of the content ideas and skills that are supposed to be learned in the basic and in the advanced chemistry courses. Also, some reference to expected pre-requisites from science studies in middle school is included. This is to demonstrate the value of the general definition and the assessment tools to measure any chemistry curriculum, and their ability to link what is actually been taught in those courses to students' manifestation of chemical literacy.

The contribution of the basic course to various levels of chemical literacy

Nominal literacy

The analysis of students' acquaintance with various chemical concepts pre and post the basic course is presented in Table 5.

Table 5. Differences between means, representing acquaintance with chemical concepts, pre and post the basic course (on a 1-3 scale).

Category	**Pre basic course (N=422)**	**Post basic course (N=338)**		
	Mean (SD)	**Mean (SD)**	**t**	**p**
Scientific inquiry	2.45 (0.41)	2.61(0.42)	5.32	≤ 0.0001
Structure: sub-micro concepts	2.43 (0.45)	2.76 (0.37)	11.14	≤ 0.0001
Materials: general types of substances	2.46 (0.33)	2.50 (0.36)	1.60	NS
Materials: specific substances	2.69 (0.35)	2.71 (0.35)	0.84	NS
Chemical reactions	2.12 (0.50)	2.43 (0.45)	8.75	≤ 0.0001

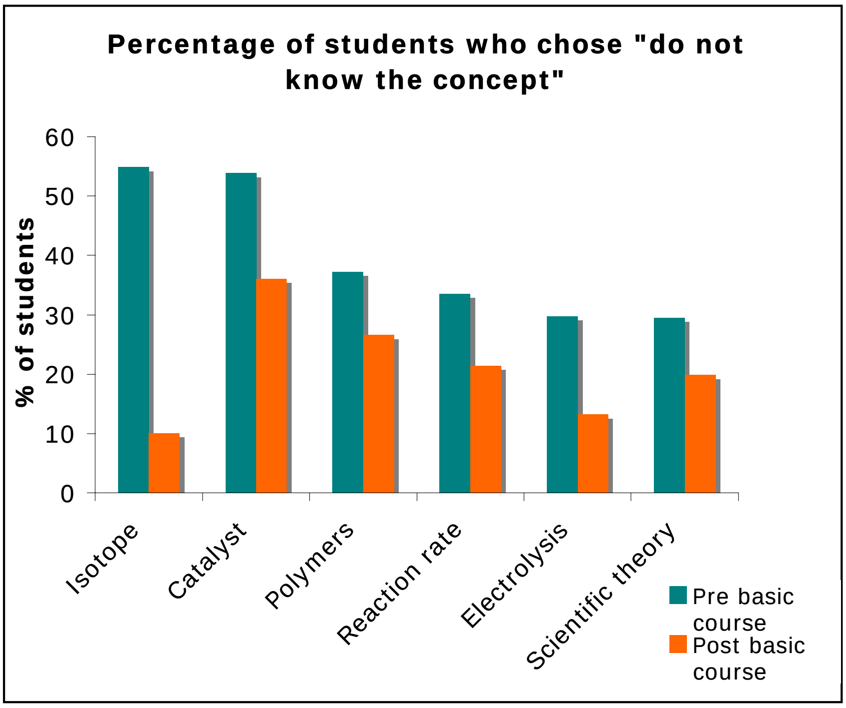
The relatively high means for most categories (around 2.5), presented in Table 5, indicate that most of the students were already familiar with many chemical concepts at the beginning of the basic course. This is true especially for concepts included in the following categories: scientific inquiry, sub-micro concepts, general types of substances, and specific materials. It is suggested that many concepts in these categories were familiar from science studies in middle school (for example: atom and molecule), and from daily life (for example: air). Concepts that were included in the 'Chemical reaction' category were less familiar to the students (mean 2.1) at the beginning of the basic course. No significant differences were found regarding the categories 'General types of substances' and 'Specific materials'. This can be explained by the fact that many items were already rated at the maximal level in the pre-test by most students, especially in the category of "specific materials" (items such as air, ozone, and metal), whereas other items were less familiar at the beginning of the course and remained that way, since they were not addressed in the syllabus of the basic course and were not discussed during the course. To sum up, comparing the results of students at the beginning of the basic course (10^{th} grade) and at the end of it (same classes) revealed a significant improvement in students' acquaintance with concepts included in three out of five categories.

The growing acquaintance with chemical concepts is also demonstrated in the change of percentage of students, who chose specific concepts as unfamiliar. Table 6 and Figure 1 present the change of degree of acquaintance for those chemical concepts that were un-familiar to 30% of the students of the basic chemistry course at the pre-test.

Table 6. Most unfamiliar concepts.

Percentage of students who chose *'do not know the concept'*					
Category	**Specific concept**	**Pre basic course (N=429)**	**Post basic course (N=343)**	**Chi^2 value (df=1)**	**p**
Sub-micro concepts	Isotope	54.89	10.09	165.0	≤ 0.001
Scientific concept	Scientific theory	29.54	19.88	9.1	≤ 0.05
Types of substances	Polymers	37.26	26.65	9.5	≤ 0.05
Chemical reactions	Electrolysis	29.74	13.25	28.7	≤ 0.001
	Reaction rate	33.57	21.39	13.5	≤ 0.001
	Catalysts	53.86	36.04	23.6	≤ 0.001

Figure 1. Percentage of students who chose 'do not know the concept'.



As Table 6 and Figure 1 demonstrate, a significant decrease in the number of students who did not recognize the concepts is observed. For example, 54.9% of the students reported that they were not familiar with the concept 'Isotope' before the basic course, whereas only 10% of students said so in the post test. The same trend is found for all concepts that were the less familiar at the beginning of the basic course.

The overall picture indicates that the basic chemistry course definitely contributes to the nominal level of chemical literacy, namely the acquaintance with chemical concepts.

Functional literacy

Students' explanations to various chemical concepts were categorized as (1) wrong or meaningless answers, (2) partially correct i.e. containing some correct elements, but not accurate or complete, and (3) correct. A second phase of categorization checked whether the students' explanation contained molecular or macro terms, and whether it included some elements of chemical language (a symbol, or a drawing of a molecule). Eventually, the assessment consisted of six categories: correct, partially correct, and wrong molecular explanation, and correct, partially correct, and wrong macro explanations. A chi^2 analysis was used in order to indicate whether there is a significant difference in the distribution of answers before and after the basic course regarding each concept. Table 7 presents the percentage of students providing correct and partially answers. The percentage of wrong answers is not presented in Table 7, but it was taken into consideration in the chi^2 analysis

Table 7. Students' explanations of chemical concepts.

Concept	**Type of explanation**	**Percentage of correct explanation (N=259)**		**Percentage of partially correct explanation (N=223)**		chi^2 **value (df=5)**	**p**
		Pre basic course	**Post basic course**	**Pre basic course**	**Post basic course**		
molecule	Molecular	45.90	43.92	37.99	40.39	2.13	NS
	Macroscopic	-	-	4.25	3.92		
	Total	**45.90**	**43.92**	**42.24**	**44.31**		
chemical reaction	Molecular	0.40	4.70	5.93	8.55	19.38	≤ 0.05
	Macroscopic	1.98	5.56	69.17	66.24		
	Total	**2.38**	**10.26**	**75.10**	**74.79**		
acid	Molecular	1.79	2.41	1.79	6.02	32.34	≤ 0.05
	Macroscopic	13.10	33.73	50.00	29.52		
	Total	**14.89**	**36.14**	**51.79**	**35.54**		
ozone	Molecular	1.62	5.30	1.29	3.41	20.35	≤ 0.05
	Macroscopic	36.25	34.09	45.63	50.76		
	Total	**37.87**	**39.39**	**46.92**	**54.17**		
chemical bond	Molecular	3.85	8.33	41.83	43.14	11.29	≤ 0.05
	Macroscopic	1.44	2.94	30.77	31.86		
	Total	**5.29**	**11.27**	**72.60**	**75.00**		
temperature	Molecular	1.05	4.65	2.80	1.40	11.58	≤ 0.05
	Macroscopic	3.15	0.93	22.38	18.60		
	Total	**4.20**	**5.58**	**25.18**	**20.00**		

The results presented in Table 7 indicate some interesting trends:

- The percentage of students who provided a correct answer both before and after the basic course is relatively low and does not exceed a total of 50%.
- For all items, except 'molecule' and 'temperature', most students provided answers that were categorized as partially correct, i.e. containing some correct elements, but not accurate or complete answers.
- In general, students tend to explain concepts at the macroscopic level more than the molecular one, both pre and post the basic course.
- Chi^2 analysis revealed that for all concepts, except molecule, there is a significant difference in the distribution of answers pre and post the basic course.

In cases where a significant difference was found, a post-hoc multiple comparison in sample proportions was conducted in order to identify the causes for the difference in distribution (Marasculio and McSweeney, 1977).

It was clear from students' answers, at the end of the basic course, that they have more knowledge regarding specific items, and that they use a richer chemical vocabulary. However, their answers demonstrate that most of them could not use this knowledge correctly. For example, by the end of the basic course some students explained the concept 'molecule' without referring to the molecular level: "*It is combined of one or few elements"; "it determines the properties of matter"; "non-metallic elements are molecular elements"*. These answers, although not reflecting any understanding at the molecular level, demonstrate that students acquired some knowledge. In addition, most students (81.2% before, and 86.8% after the basic course) referred to the inner structure of the molecule, for example *"Molecules consist of few atoms"*. Such explanations were categorized as 'zoom in'. Only a small percentage of the student population (5.2% in the pre test and 4.8% in the post test) referred only to a 'zoom out' aspect, such as *"a molecule is the building block of matter"*. About 13.5% of the students before the basic course and 8.4% of the students after it referred to both aspects. This finding suggests that the students' understanding of the concept molecule is rather limited, and that they have difficulties in relating their understanding to wider conceptual schemes of structure of matter ('zoom out'). However, further research is needed in order to establish such assertion.

Even wrong explanations provided indication of the use of newly acquired knowledge. For example, students' wrong explanation of the concept 'chemical reaction': *"A chemical reaction occurs when the reactants react with the products"*; or *"A chemical reaction is when you write reactants, then an arrow, and finally you write the products. You should also balance it"*. These explanations show that the students used newly acquired knowledge, but were not able to demonstrate any deep understanding of the concept.

It is possible that the use of macroscopic explanations rather than molecular ones, and the fact that most of the answers provided by the students were categorized as 'partially correct' and not as 'correct' answers, can also result from some limitations of the assessment tool. The instructions were quite general*: "Explain in your own words, or define the following concepts"*. This general approach was chosen in order to address students' ideas, and not 'lead them' toward a desired type of answers. A more specific phrasing, such as "*use molecular terms in your explanation, whenever possible*" could have provided different results, but then the interpretation of the results would also be different. In addition, the tool assessed students' ability to produce explanations or definitions. This is considered to be a difficult task; therefore most students did not meet the criteria for correct and accurate answers. It is also important to note that lack of retrieval not necessarily indicates lack of knowledge (Arzi et al., 1986). It is suggested that a different task could trigger students' recall of knowledge differently. But in spite of this, it can be concluded that the immediate associative level of retrieval demonstrated by most students does not meet the functional level of '*chemical literacy*'.

Conceptual literacy

We focused on students' ability to refer to the correctness of chemical explanations to daily phenomena. Table 8 presents the results of the pre and post the basic course tests.

Table 8. Comparison of mean values regarding explanations of phenomena pre and post the basic course.

	Pre basic course		Post basic course		*t* value
	Mean	**SD**	**Mean**	**SD**	
Phenomena included in version A	**N=188**		**N=165**		
Perfume: diffusion and smelling	49.62	18.89	45.97	20.81	
Temperature	24.56	21.69	21.11	21.63	1.49 *
Burning wax	32.02	26.69	39.70	24.15	0.85 *
'Heavy water'; Isotopes	26.70	25.24	22.67	23.32	1.55 *
Limestone reacting with acid	35.18	27.26	34.80	28.10	0.90 *
Phenomena included in version B	**N=235**		**N=170**		
Cooling food	56.68	24.69	54.70	24.95	0.79 *
Conductivity	44.78	24.83	44.12	23.12	0.27 *
A rusty nail (reduction-oxidation)	24.92	23.35	29.39	24.55	1.86 *
A burning match	40.21	19.58	39.12	16.80	0.60 *
Spontaneous processes	26.38	21.45	26.40	21.82	0.01*
Water and oil	30.50	22.36	31.57	23.29	0.47 *

* Non-significant

Table 8 demonstrates that a relatively small percentage of students attained the level of conceptual chemical literacy at the end of the basic course. The students' ability to determine the correct chemical statements regarding familiar phenomena was very poor. The percentage of correct answers ranged from 21-55 at the end of the basic course. The relatively low scores imply that the task was perceived as a difficult one, and a totally different task from that usually practised in class. Also, some items contained chemical knowledge that is not discussed during the basic course. The results indicate that by the end of the basic course most students still lack the ability to use the knowledge they acquired in their chemistry studies in different contexts, such as explanations of daily phenomena. The basic chemistry course does not contribute to this ability, since there were no significant differences in students' scores pre and post the basic course.

It can be concluded that the main achievement of the basic chemistry course is significantly improving students' nominal literacy. While this level is considered as non-sufficient, it is important to keep in mind, that achieving chemical literacy for all is not always the main goal of teaching. For some teachers, the main goals for the basic course are locating the students who are interested in studying the advanced course, and provide those with the basic knowledge they need (Shwartz et al., 2005).

The contribution of the advanced chemistry course to the various levels of chemical literacy

By the end of the basic course (10^{th} grade) students can choose to enroll in a more advanced course in science, or quit science learning. It is reasonable to assume that the advanced chemistry course will further develop the chemical literacy of students completing it. However, we were interested in identifying the specific contributions of the advanced course. To address this goal, we compared students' achievements at the end of the basic course (end of 10^{th} grade), the middle of the advanced course (11^{th} grade), and at the end of the advanced course (12^{th} grade). Naturally, the population of students taking the basic course (10^{th} grade) was found to be heterogeneous. It was decided to use for this comparison only the achievements of those 10^{th} graders who opted to study science as a major during 11-12^{th} grade. The basis for comparison was obtained by an analysis that revealed that this group is similar to the advanced level group in their attitude toward chemistry learning (Shwartz, 2004). Since these groups were found to be similar in terms of attitudes toward chemistry learning, it seemed logical to compare the contribution of further learning to various levels of chemical literacy. For analysis of variance, we used a general linear models procedure (Duncan's multiple range test) (Winer, 1971).

Nominal literacy

Table 9 presents the development of students' acquaintance with chemical concepts.

Table 9. Comparison of mean values regarding acquaintance with chemical concepts, (on a 1-3 scale)

Group	Group 1	Group 2	Group 3		
	End of basic course (10^{th} grade) N=217	End of 3 units (11^{th} grade) N=158	End of 5 units (12^{th} grade) N=164	F value	p (*)
Category	Mean (SD)	Mean (SD)	Mean (SD)		
Scientific concepts	2.67 (0.37)	2.61 (0.39)	2.72 (0.31)	3.69	≤ 0.05
Sub-micro concepts	2.85 (0.28)	2.81 (0.35)	2.91 (0.16)	5.20	≤ 0.01
General types of substances	2.55 (0.31)	2.56 (0.30)	2.68 (0.22)	5.30	≤ 0.01
Specific substances	2.73 (0.33)	2.69 (0.38)	2.73 (0.28)	0.80	NS
Chemical reaction	2.49 (0.41)	2.56 (0.43)	2.80 (0.27)	34.62	≤ 0.001

* In all cases: Group 3 > Groups 1, 2

The mean values of all three groups express a high level of acquaintance with chemical concepts. By the end of the advanced course there is a significant improvement in the acquaintance with chemical concepts. This claim is supported by the Duncan's multiple range test results. Students at the middle of 11^{th} grade are not significantly different from those at the 10^{th} grade. One explanation to this finding can be the lack of alignment between the assessment tool and the curricular sequence: about 2/3 of the items in this test should already be familiar to them in 10^{th} grade and about 1/3 of them are part of the syllabus of the 12^{th} grade (for example: polymers, reaction rate, and protein). Only three items in the list are introduced in 11^{th} grade (acid, base, and oxidation). The emphasis of 11^{th} grade studies is on stoichiometry, which is not regarded as essential for basic chemical literacy; therefore, 11^{th} grade students probably know more chemistry than 10^{th} grade graduates, but are similar to them in terms of nominal chemical literacy requirements. This finding can also be explained by the fact that the assimilation of many new chemical concepts is not immediate. Although students learn or hear about concepts in 11^{th} grade, a real understanding is not achieved immediately, but only after a few months. Regarding the category of 'Specific substances', all groups rated it almost maximally, as most items included in this category are well known from daily life (air, ozone, steel, carbon).

Functional literacy

Table 10 presents the finding regarding student's ability to provide a correct explanation of chemical concepts.

Table 10. Percentage of correct explanations of chemical concepts, at each level of chemistry study.

Concept	Type of explanation	Percentage of correct explanation			
		1 End of Basic course (N=217)	2 11^{th} grade (N=158)	3 12^{th} grade (N=164)	p (*)
molecule	Molecular	45.95	40.00	52.35	NS
	Macroscopic	–	1.38	1.34	NS
	Total	45.95	41.38	53.69	NS
chemical reaction	Molecular	5.88	9.45	16.34	NS
	Macroscopic	6.47	7.87	31.37	≤0.05 3>1,2
	Total	12.35	17.32	47.71	≤0.05 3>1,2
acid	Molecular	2.27	34.51	45.18	≤0.05 3,2 >1
	Macroscopic	37.88	33.63	34.94	NS
	Total	40.15	68.14	80.12	≤0.05 3>1,2
ozone	Molecular	7.07	9.21	12.34	NS
	Macroscopic	40.76	32.24	34.42	NS
	Total	47.83	41.45	46.76	NS
chemical bond	Molecular	10.00	10.77	13.43	NS
	Macroscopic	2.00	-	2.24	NS
	Total	12.00	10.77	15.67	NS
temperature	Molecular	5.06	2.48	11.72	≤0.05 3>1,2
	Macroscopic	1.27	-	16.55	≤0.05 3>1,2
	Total	6.33	2.48	28.27	≤0.05 3>1,2

(*) The significance of the difference was established by a post-hoc multiple comparisons analyzing sample proportion

For three out of six concepts there was a significant increase in the students' ability to explain them correctly. The percentage of explanations containing the molecular level also increased in some cases. These findings mean that the advanced course contributes to the functional chemical literacy of the students.

The concept *chemical bonding* is exceptional. It is a fundamental concept in understanding what chemistry is about; it is discussed several times and at various levels during the advanced course, but still, very few students (15.7%) provided an explanation expressing a profound understanding of it. Most students in the advanced course (both 11^{th} and 12^{th} grade) provided examples of chemical bonds, but did not explain the essence of the concept. Typical answers were, *"It is a bond inside molecules and between molecules"; "Ionic, metallic, covalent, van der Waals, and hydrogen bonds are chemical bonds"*. This kind of answer was classified as 'partially correct' but not as 'correct and accurate' since the answers do not provide any explanation of the essence of the concept. This does not necessarily mean that students who provided this kind of explanation really do not know what a chemical bond is. It is more likely that they were never asked to explain the meaning of it. The usual practice in the advanced course is to focus on the differences between bonds (for example, Van der Waals bonds are weaker than hydrogen bonds) rather than explain the common basis of all chemical bonds. Understanding that a chemical bond is based on the electrical attraction between particles is considered to be more important for chemical literacy, rather than citing the names of bonds (Levy-Nahum et al., 2004). Thus, we think it advisable to emphasize the general nature of chemical bonds, before teaching about the many types of chemical bonding as disconnected pieces of knowledge.

Students' interviews, conducted by the end of the advanced course, also revealed that students themselves do not perceive the nominal level of literacy as sufficient. They expect the chemistry course to provide them with functional literacy regarding a range of relevant concepts. For example, in referring to the concept 'protein' (which is not a core concept in the advanced course syllabus), one student complained:

"As a student who learned at the advanced level, I cannot say anything about proteins and how they are built, not even the basic facts. So, if this is my situation after 3 years of learning chemistry and after taking the matriculation examination, it makes me feel bad. I think that chemistry studies should provide me with the basics, with the ability to explain…"

It could be concluded that the advanced chemistry course has definitely contributed to the achievement of the functional level of '*chemical literacy*', since the percentage of students providing correct answers has increased, as well as students' use of molecular terms.

Table 11. Comparing the mean values regarding explanations of chemical phenomena.

	Group 1 End of 10th grade	**Group 2 11th grade**	**Group 3 12th grade**		
Phenomena included in version A	**Mean (S.D.) N=109**	**Mean (S.D.) N=74**	**Mean (S.D.) N=72**	**F value (2,255)**	**p Duncan's multiple range test**
Perfume: diffusion and smelling	48.10 (21.70)	53.86 (18.25)	55.95 (18.69)	3.83	≤ 0.05 3>1
Temperature	21.25 (21.74)	29.28 (24.64)	33.10 (22.98)	6.32	≤ 0.01 3,2>1
Burning wax	31.56 (25.28)	36.76 (25.00)	50.00 (26.00)	11.61	≤ 0.001 3>2,1
Heavy water; Isotopes	25.32 (23.35)	38.38 (25.16)	41.11 (25.32)	11.06	≤ 0.001 3,2>1
Limestone reacting with acid	40.50 (29.06)	52.51 (29.73)	64.68 (25.60)	15.98	≤ 0.001 3>2>1
Phenomena included in version B	**Mean (S.D.) N=110**	**Mean (S.D.) N=87**	**Mean (S.D.) N=79**	**F value (2, 276)**	**P Duncan's multiple range test**
Chilling food	59.27 (23.29)	61.84 (22.75)	77.21 (20.93)	16.09	≤ 0.001 3>2,1
Conductivity	48.64 (21.10)	54.02 (17.83)	81.01 (20.10)	66.28	≤ 0.001 3>2,1
A rusty nail (reduction-oxidation)	32.54 (32.54)	39.96 (24.59)	60.29 (28.60)	27.72	≤ 0.001 3>2,1
A burning match	41.93 (15.94)	44.11 (17.86)	53.80 (17.49)	11.98	≤ 0.001 3>2,1
Spontaneous processes	25.45 (21.34)	29.88 (21.68)	43.35 (20.98)	16.77	≤ 0.001 3>2,1
Water and oil	34.24 (23.22)	47.89 (24.08)	53.80 (23.10)	17.59	≤ 0.001 3,2>1

Conceptual literacy

Table 11 presents the development in students' ability to determine the correctness of chemical explanations. Note that both versions were administered in each class, intending that 50% of the students would answer each of them. However, the differences in N's are a result of slight differences in the number of students that actually responded to each version. The relatively high value of the standard deviation could be explained by the fact that the 10^{th} grade population is rather heterogeneous.

The results, presented in Table 11, clearly indicate a significant improvement in students' ability to evaluate the correctness of chemical explanations. By the end of the advanced course, students' scores were significantly higher than the other two groups. On the other hand, the absolute means for most phenomena remained relatively low. The relatively low scores imply that the task was perceived as a difficult one by students in all grades. The percentage of *"I don't know"* answers (average value for all items) also decreases from 37% at the end of basic course to 20% at the end of advanced course.

A significant improvement was observed in the achievements of 12^{th} grade students, regarding nominal, functional, and conceptual levels of chemical literacy. However, regarding students' ability to determine the correct chemical explanations - the absolute scores remained relatively low. The relatively low scores at the conceptual level suggested that the level of multidimensional literacy could be only partially met. However, a specific aspect of reading comprehension was chosen, as will be described in the next section.

Multi dimensional literacy – reading and analyzing a written article (short unseen paragraph)

Multi-dimensional scientific literacy means that students develop some understanding and appreciation of science and technology, and its relationship to their daily lives. More specifically, students begin to make connections within and between scientific disciplines, and between science, technology and the larger issues that challenge our society (Bybee 1997). Assessing all aspects of multi-dimensional chemical literacy is probably very complex and is beyond the purposes of the current research. The assessment of this level was limited to a very specific aspect, namely the students' ability to read and understand a short article, that links between chemistry and personal or social aspects was assessed. The ability to read, to understand, to relate the new information to previous knowledge, to criticize, and to ask additional questions are important components of the skills dimension in the chemical literacy definition.

The assessment tool used to assess this level of chemical literacy was described in detail in the methodology section. As three articles were distributed in each class randomly, a two-way analysis of variance (ANOVA) was conducted in order to reveal whether there are significant differences between the responses to the articles. The analysis revealed differences between students' scores in the different articles. This means that the level of tasks were different in different articles. This was in spite of the fact that the texts were revised by four judges who agreed that coping with the three versions required a similar level of reading comprehension and chemistry knowledge. In addition, some questions were actually identical, for example, *"Explain in your own words what are the main ideas presented in the article."* The fact that eventually the articles were found to be significantly different, indicates the problematic nature of assessing textualized knowledge: the reader-response theory suggests that the reader and its orientation to the text are dominant factors in the construction of meaning; therefore, different texts triggered student's response differently (Morrow and Gambrell, 2000). Resulting from this, students' achievements regarding each version are presented, and the general trend is discussed, and not the absolute values. The results are presented in Table 12.

Table 12. Results of reading an unseen text (on a 1–3 scale).

Ability assessed:		**1 10th grade (N=22)**	**2 11th grade (N=40)**	**3 12th grade (N=42)**	**p Duncan's multiple range test**
Reading comprehension	Green chemistry	2.75	2.64	2.76	NS
	Mankind and materials	1.70	1.63	1.56	NS
Relating to former chemical knowledge	Green chemistry	1.96	2.26	2.51	<0.05 3>1
	Mankind and materials	2.40	2.54	2.63	NS
	Health issues and advertisements	2.75	2.84	2.80	NS
Reasoning	Green chemistry	2.06	1.83	1.82	NS
	Mankind and materials	1.36	2.20	2.32	<0.01 3>1
	Health issues and advertisements	1.96	1.94	2.28	NS

For most of the categories, no significant differences exist between the three groups for any of the three administered versions. In addition, there were similarities in students' ability at all levels to list the key words in each article: most students' lists contained 3-7 key words. Only a few of them mentioned 1-2 key words or more than 8 words. The key words, mentioned by each of the groups, were almost identical. The similarity in results can be explained by the fact the reading articles is not obligatory in the current chemistry program (either in basic or advanced), therefore, most students, at all levels of teaching, were unfamiliar with this kind of task, and presented similar responses. In a few cases, 12th grade students demonstrated more articulated responses. For example, regarding the "Green Chemistry" paragraph, students were asked to explain what a catalyst is, and why catalysts were used in the specific example given in the paragraph. Since this concept is introduced only at the end of 11th grade (or the beginning of 12th grade), there was a significant improvement in the students' ability to answer this question.

Discussion and summary

Based on the results obtained in the current study, the basic chemistry course contributes mainly to the nominal level of chemical literacy. There was a significant improvement in the students' declaration that they know chemical concepts and understand them. This means that most students finishing the basic course have some idea of what an atom is, have heard about acids, and can say something intelligent regarding the ozone layer. Students declared that they have heard of many chemical concepts, and understand their meaning. Although this level of literacy is not considered as sufficient, it is an important finding, since a feeling of familiarity and various forms of recall (not necessarily accurate forms) are important for future coping with chemistry-related issues (Arzi et al., 1986).

The assessment of students' ability to define some chemical concepts revealed that only a small percentage of them achieved the functional level of chemical literacy, namely, the ability to define a concept correctly. Are they learning any chemistry? Yes, they are. In their explanations at the end of the basic course, students used many new terms such as covalent or ionic bonding, reactants, and products, terms that did not appear in their explanation in the pre-test. The problem is that the newly acquired knowledge is not well assimilated, and thus does not contribute meaningfully to the students' ability to explain basic chemical concepts.

Conceptual chemical literacy was assessed by the ability of students to determine the correctness of chemical explanations of daily phenomena. The score ranged between 21% and 55%, which means that the majority of students did not attain this level of literacy. There were no significant differences between students' achievement before and after the basic course, from which it can be inferred that the basic course does not contribute to the students' ability to refer to complex phenomena. This could be a result of introducing chemical concepts and topics without sufficient links connecting them. For example: the law of conservation of mass has been utilized mainly in balancing equations of chemical reactions. The fact that the combustion of carbohydrates results in the formation of H_2O and CO_2 is also usually discussed during the laboratory practice, and the products are being identified using specific indicators. However, linking the two pieces of knowledge - conservation of mass to combustion reactions, by being able to explain 'where did the wax disappear' – was found to be a difficult task for the students. The findings regarding critical reading of an article indicates that students understood what they read (reading comprehension) and could relate to former chemical knowledge, if they were requested to do so. However, they demonstrated a relatively low level of reasoning abilities.

One of the explanations of students' performances could be that the basic chemistry course is perceived as preparatory for the next level of learning and not as an educational entity in itself. This means that students are introduced to a relatively narrow aspect of chemistry; they learn concepts theoretically and become acquainted with elements of the language of chemistry, which would probably be useless for most students in their future lives. Teachers assume that a more general view of chemistry will be acquired later, in the next level of learning. (For more details on teachers goals and beliefs regarding chemistry teaching see Shwartz et al., 2005.) Rethinking the content and emphasis of the basic course is needed if we are to promote chemical literacy for **all** students.

The advanced chemistry course significantly improves the achievements of students, regarding nominal, functional, and conceptual levels of chemical literacy. However, the absolute means remain relatively low. The improvement in their reading comprehension and reasoning skills is also limited. It is important to keep in mind that reading and referring to written paragraphs were not compulsory at the chemistry program taught at the time of the assessment, and therefore not a part of the skills assessed by the matriculation examination. Therefore, teachers tend to ignore this aspect, and concentrate on exercises that would directly contribute to their students' success in the final examination (Levy-Nahum et al., 2004), so it was probably an unfamiliar task to all the participating students. The fact that students of all levels of chemistry could cope reasonably well with such a task without previous experience is encouraging; it implies that addressing critical reading and reasoning in classroom directly would provide students with the opportunity to develop further these aspects of chemical literacy.

These results are in accord with findings regarding biological literacy, and support the common argument that the science program in high school leads to a functional level of literacy (BSCS, 1993). This level can be achieved by memorizing definitions of concepts, but does not necessarily reflect profound understanding.

It can be concluded that the criteria for the high levels of literacy, as defined within the framework of this study, are only partly attained. This is especially true for those students who do not take the advanced course. Since most high-school graduates (about 80%) do not take this course, it can be concluded that the demonstrated level of chemical literacy of most future citizens is rather limited.

Attaining a higher level of literacy by all students (not only those who major science), requires a change in the emphases of chemistry content, pedagogy and curriculum. Placing the achievement of conceptual and multi-dimensional chemical literacy as a teaching goal also in the basic course would result in a higher level of chemical literacy. Since the basic course has to address the needs of two different populations, those who continue with their science studies, and those who quit after the basic course, two different 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 the chemical literacy of the general public. On the basis of this platform, additional short units will provide a deeper and more detailed introduction to the same chemical content; these units would be optional. Another option, of course, is to provide two different courses on 10th grade, but this approach has the disadvantage of students having to decide whether they are 'science oriented' or not, in a relatively young age, and without sufficient science experiences to back-up this decision.

If indeed, attaining chemical literacy is perceived as an important goal, then the advanced chemistry course should also aim at achieving all aspects of chemical literacy. If some of those students are the potential future scientists, it is a logic requirement that they would be chemically literate. Such changes include presenting a wide range of chemical ideas; emphasizing the main ideas and not the specific details; increasing the relevance of chemistry studies; making efforts to better organize students' knowledge; focusing on the development of high-order learning skills; and finally maintaining the interest and needs of all students. Chemistry studies in Israel currently undergo structural as well as curricular changes in order to address the goals of chemical literacy to all students. For example, a critical reading item would be an obligatory item in the final matriculation examination starting next academic year. It is a short scientific paragraph that students have to read and to answer a few questions related to it. It is expected that teachers will now focus on reading skills of their students in order to ensure success in the examination, which will probably result in promoting this aspect of chemical literacy.

This study demonstrates the value of assessing the impact of a specific curriculum on the manifestation of different aspects of chemical literacy. However, the importance of this study goes beyond assessing the contribution of a specific course to chemical literacy. It is suggested, that the study contributes to the efforts to establish a coherent framework, and to develop and validate assessment tools for assessing chemical literacy. One of the challenges in science education research is to create a link between theoretical frameworks and taxonomies to practical assessment. In this research an attempt was made to use the theoretical frameworks of chemical and scientific literacy, in order to assess various aspects of chemical literacy among high-school students.

The design of the assessment tools was research-driven rather than curriculum-driven (aiming at the learning goal of a specific curriculum). As such, they allow a relatively objective comparison between different chemistry curricula, and various teaching approaches. It is recommended that future assessment of the benefits of new curricula, or new approaches such as inquiry-based approach, will utilize the framework and assessment tools presented here.

References

Aikenhead S.G. and Ryan A.G., (1992), The development of a new instrument: Views on Science-Technology-Society" (VOSTS), *Science Education*, **76**, 477-491.

American Association for the Advancement of Science (AAAS) (1993), *Benchmarks for science Literacy*, New York, Oxford University Press.

Arzi H.J., Ben-Zvi R. and Ganiel U., (1986), Forgetting versus savings: the many facets of long-term retention, *Science Education*, **70**, 172-188.

Atkins P.W., (2005), Skeletal chemistry, *Education in Chemistry*, **42**, 20, 25; see also: http://www.rsc.org/Education/EiC/issues/2005_Jan/skeletal.asp

Backer S., (2001), Mathematical and scientific literacy in PISA: The OECD program for international student assessment. In: O. De Jong, E.R. Savelsbegh, and A. Albas (Eds.), *Teaching for scientific literacy: context, competency, and curriculum,* Proceedings of the 2nd international Utrecht/ICASE symposium, Utrecht, The Netherlands.

Biological Science Curriculum Studies (BSCS), (1993), *Developing biological literacy*, Dubuque, IA, Kendall Hunt Publishing Company, pp. 1-25.

Bybee R.W., (1997), *Achieving scientific literacy: from purposes to practices*, Portsmouth, NH, Heinmann Publishing, pp. 82-86.

Champagne A. and Newell S.T., (1992), Directions for research and development: alternative methods of assessing scientific literacy, *Journal of Research in Science Teaching*, **29**, 841-860.

Champagne A., (1997), *Assessment of science literacy standards: assessment in the service of education,* Proceedings of a symposium – Globalization of science education – International conference on science education moving towards science education standards, Seoul, Korea.

Champagne A.B. and Kouba V.L., (1998), *Literacy in the National Science and Mathematics Standards: communication and reasoning*, Albany, NY, Center of English Learning and Achievement.

Duschl R. and Osborne J., (2002), Supporting and promoting argumentation discourse in science education, *Studies in Science Education,* **38**, 39-72.

Fensham P.J. and Harlen W., (1999), School science and public understanding of science, *International Journal of Science Education*, **21**, 755-763.

Harlen W., (2001), The assessment of scientific literacy in the OECD/PISA project, *Studies in Science Education*, **36**, 79-104.

Holman J., (2002), What does it mean to be chemically literate? *Education in Chemistry*, **39**, 12-14.

Korpan C.A., Bisnaz G.L. and Bisnaz J., (1997), Assessing literacy in science: evaluation of scientific new briefs, *Science Education*, **81**, 515-532.

Laugksch R.C. and Spargo P.E., (1996a), Development of a pool of scientific literacy test-items based on selected AAAS literacy goals, *Science Education*, **80**, 121-143.

Laugksch R.C. and Spargo P.E., (1996b), *Scientific literacy test items*, Cape Town, SA, University of Cape Town.

Levy-Nahum T., Hofstein A., Mamlok-Naaman R. and Bar-Dov Z., (2004), Can final examinations amplify students' misconceptions in chemistry?, *Chemistry Education: Research and Practice,* **5**, 301-325.

Marasculio L.A. and McSweeney M., (1977), *Nonparametric and distribution-free methods for the social sciences*, Brooks Cole Publishing Company, Monterey, CA, pp. 141-147.

Morrow L.M. and Gambrell L.G., (2000), Literature-based reading instruction. In: M.L. Kamil, P.B. Mosenthal, P.D. Pearson and R. Barr (Eds.), *Handbook of reading research*, London, Lawrence Erlbaum Associates publishers, pp. 563-586.

National Center for Education Statistics (NCES), (2006), *Trends in International Mathematics and Science Study* (TIMSS), http://nces.ed.gov/TIMSS/ .

National Research Council (NRC) (1996), *National science education standards*, Washington DC, National Academy Press.

Norris S.P. and Philips L.M., (1994), Interpreting pragmatic meaning when reading popular reports on science, *Journal of Research in Science Teaching*, **31**, 947-967.

Norris S.P. and Phillips L.M., (2003), How literacy in its fundamental sense is central to scientific literacy, *Science Education*, **87**, 224-240.

Organization for Economic Co-operation and Development (OECD-PISA) (last revised 2005), *Assessment of scientific literacy in the OECD* / Pisa project, http://www.pisa.oecd.org/

Pella M.O., (1976), The place of function of science for a literate citizenry. *Science Education*, **60**, 97-101.

Phillips L.M. and Norris S.P., (1999), Interpreting popular reports of science: what happens when the readers' world meets the world on paper?, *International Journal of Science Education,* **21**, 317-327.

Scribner S., (1986), Literacy in three metaphors. In N. Stein (Ed.) *Literacy in American Schools: learning to read and write*, pp 7-22, Chicago, IL: University of Chicago Press, Shamos M.H., (1989), Views of scientific literacy in elementary schools science programs: Past, present and future. In: A.B. Champagne and B.E. Lovitts (Eds.) *The year in school science 1989: scientific literacy*. Washington DC: American Association for the Advancement of Science (AAAS).

Shamos M.H., (1995), *The myth of scientific literacy*, New Brunswick, NJ, Rutgers University Press.

Shen B., (1975), Science literacy and the public understanding of science, In S.B Day (Ed.), *Communication of scientific Information*, Basel: Karger, AG.

Shwartz Y., (2004), *Chemical literacy: defining it with teachers, and assessing its expression at the high-school level*, PhD dissertation, Department of Science Teaching, The Weizmann Institute of Science.

Shwartz Y., Ben-Zvi R. and Hofstein A., (2005), The importance of involving high-school chemistry teachers in the process of defining the operational meaning of 'chemical literacy', *International Journal of Science Teaching,* **27**, 323-344.

Shwartz Y., Ben-Zvi R. and Hofstein A., (2006), Chemical literacy: what it means to scientists and school teachers?, *Journal of Chemical Education,* **83**, 1557-1561.

Simon S., Erduran S. and Osborne J., (2006), Learning to teach argumentation: research and development in the science classroom, *International Journal of Science Education,* **28,** 235-260.

Solomon J. and Thomas J., (1999), Science education for the public understanding of science, *Studies in Science Education,* **33**, 61-90.

The Ministry of Education and Science, (1992), *Tomorrow 98:* A report of superior committee for science and technology education, Jerusalem, (English Version).

Wandersee J.H., (1988), Ways students read text, *Journal of Research in Science Teaching*, **25**, 69-84.

Winer B.J., (1971), *Statistical principles in experimental design*, McGraw-Hill Book Company, NY.

Yfrach M., (1999), *Definition of chemical literacy and assessment of its attainment in high school chemistry*, Unpublished M.Sc. Dissertation, Weizmann Institute of science, Rehovot, (In Hebrew).

Zuzovsky R., (1997), Assessing scientific and technological literacy among sixth graders in Israel. *Studies in Educational Evaluation*, **23**, 231-256.