Journal of the Serbian Chemical Society

JSCS-info@shd.org.rs • www.shd.org.rs/JSCS

ACCEPTED MANUSCRIPT

Journal of the Serbian Chemical Society
JSCS-info@shd.org.rs • www.shd.org.rs/JSCS
J. Serb. Chem. Soc. **00(0)**1-13 (2022)
JSCS–11415
Original scientific paper
Published DD MM, 2022

Do Serbian high school students possess knowledge of basic chemical facts related to real life as a prerequisite for chemical literacy?

FILIP STAŠEVIĆ[1], NASTA MILETIĆ[2], JELENA ĐURĐEVIĆ NIKOLIĆ[1]* and IVAN GUTMAN[1]

[1]*University of Kragujevac, Faculty of Science, Radoja Domanovića 12, 34000 Kragujevac, Serbia and* [2] *Gymnasium Kosovska Mitrovica, Lole Ribara 29, 38220 Kosovska Mitrovica, Serbia*

(Received 26 November 2021; Revised 21 November 2022; Accepted 22 November 2022)

Abstract: For a long time, literacy has had a deeper meaning than just the ability of reading and writing. Chemical literacy, as a part of science literacy, represents the use of chemical knowledge and skills in solving real life problems. With the increasing influence that chemistry has on society, chemical literacy becomes one of the main goals of science education. In order to examine the knowledge of chemical facts related to real life (as a prerequisite for chemical literacy) of high school students (N = 379), we designed a knowledge test and constructed a scoring scale for evaluating achievements. The obtained results are contrary to expectations, *i.e.* a large number of students did not achieve a satisfactory level of knowing selected chemical facts chosen by the authors. The small number of correct answers per question indicates that the examined sample of students does not show a desirable level of chemical knowledge, implying that there is a need for new, improved, strategies in chemistry teaching.

Keywords: chemistry teaching; students' achievements; basic chemical knowledge

INTRODUCTION

Literacy, in its most common usage, is defined as the ability to read and write.[1] In the 21st century, we can say that this definition is not appropriate and that the concept of literacy is much broader. Literacy is a characteristic needed not just for highly educated people, but due to a different organization of society, it is everyone's necessity.[2] Contemporary time shapes literacy and determines required abilities and skills. The digital age, the accelerated flow of information that quickly becomes outdated, the development of civilization and technology demand constant learning. Therefore, the definition of literacy is complex and dynamic. There are several forms of literacy: nominal, functional, conceptual, scientific, media, digital, political.[3-7] Many authors worldwide maintain that scientific

*Corresponding author E-mail: jelena.djurdjevic@pmf.kg.ac.rs; tel: +381 34 336 223
https://doi.org/10.2298/JSC211126083S

literacy should be one of the main goals of science education. The reason for this is the increasing impact of science and technology on everyday life and social, political, educational, technological, and economic advancement.[8-10]

Chemical literacy, as a part of scientific literacy, should be available to the broader public not just to chemists, which would imply the use of chemistry knowledge and skills in various situations.[11] Individuals who are chemical literate are:

1. Able to apply knowledge and skills from the chemistry domain in daily life,
2. Aware of the significance of chemistry,
3. Understand the relationship between chemistry, technology, and society.[12-16]

As one of the scientific disciplines, chemistry has an important role to help students to understand and use basic chemical facts and concepts which is one of the prerequisites for chemical literacy. Chemical literacy is needed to understand many processes and science-related issues that occur in everyday life.[17,18] Chemistry topics involve studying matter and properties of matter that are important in many disciplines such as health sciences, geography, physics, environmental science.[19,20] It is well known that chemicals can play a vital role in our daily lives. Therefore, it is necessary to enhance human conscience about chemistry, prepare the population for proper use of chemistry knowledge and provide them with the ability for long-life learning. Also, learning chemistry should not just lean on learning the content available in textbooks. Learning must be effective, by making links between chemical knowledge and real life, involving activities based on solving life problems related to chemical issues. Accordingly, published standards and benchmarks regarding content enable achieving the main goal of chemistry education, and that is chemistry literacy for all students.[21,22] The role of the teacher is to adapt the given curriculum, keeping in mind the type of class composition and student characteristics, also considering textbooks and other teaching materials, as well as the technical conditions, teaching tools and media available to the school. The chemistry curriculum in high school education describes the teaching process, goals, outcomes, contents, and educational activities. Standards of achievements define the result of that process, namely, required knowledge, skills, and attitudes for solving different societal challenges. These standards specify the results expected from all students (basic level), the results that are the basis for continuing education at the university level in areas not directly related to chemistry (intermediate level), and the results in chemistry required for further education in chemistry area (advanced level). Hence, there are three levels of standards of achievement, which are cumulative, built into each other, so that students at the advanced level satisfy the requirements from all three levels. Standards of achievements describe the qualitative and quantitative results of the teaching process and thus give the description of what students know and can do based on their overall general education in chemistry. As one of the goals of chemistry education is the functionality and applicability of knowledge, achieving a certain level of standards of achievement means achieving a certain level of functional chemical knowledge.

The program for International Student Assessment (PISA) and Trends in Mathematics and Science Studies (TIMSS) are two programs used for monitoring the progress of the skills that are essential for every child to progress through school and life. TIMSS assessments provide an insight into students' achievement in mathematics and science, using the scale that measures the students' knowledge, knowledge application, and reasoning ability.[23-25] According to testing under the Trends in Mathematics and Science Studies and obtained results (TIMSS 2011, 2015 and 2019), the average accomplishment of the Serbian students (>500) was statistically higher than the previously determined average value, which placed them at 25th (2011) 24th (2015) and 21st (2019) position on the list.[26-29] It should be noted that in these studies, participants were fourth-grade students from elementary school. PISA tends to focus on practical knowledge in action, namely recognizing questions as scientific, identifying relevant evidence, critically evaluating conclusions, and communicating scientific ideas.[30-33] The last results of scientific literacy for 15-years-old students assessed under the Program for International Student Assessment (PISA 2018) showed that a mean score (440) of students from Serbia in scientific literacy was statistically significantly below the Organization for Economic Co-operation and Development (OECD) average (489), so that the students from Serbia ranked 45th from 79 countries.[34]

Although the TIMSS results show solid achievements of younger primary school students, PISA assessment results are warning signs that we should be concerned about the scientific literacy of the country's population. Therefore, the present researchers were aimed at examining the level of basic chemical knowledge of the high school students from different school profiles using the test conceived on knowing different chemical terms and facts related to daily life.

EXPERIMENTAL

Research aims and research questions

The purpose of the present study was to provide an insight into the manifestation of various aspects of chemical literacy, such as knowing basic chemical facts related to everyday life, among high school students, without any hidden intentions, as discrediting students, and teachers. Since chemistry knowledge is important for society, research questions that guide researchers were:

1. What is the situation in high schools with students' knowledge of basic chemical facts and terms connected to real life?
2. Which level of chemical knowledge possess students based on researchers' scoring scale and the standards of achievements?
3. Is there a difference in the knowledge between Gymnasium students and Vocational school students?

Sample / Participants

Simple random sampling was used to select the participants for testing. A heterogeneous sample (N = 379) encompassed the high school students from two different types of schools in Serbia, gymnasium (N = 270) and vocational school (N = 109). The participants from gymnasium were all 4th grade high school students with an orientation to natural sciences and mathematics, whereas participants from three vocational schools were 1st grade (economic school, N = 28) 2nd grade (medical school, N = 52) and 4th grade (technical school, N = 29) high school students. Chemistry course as a general-educational subject lasts a different number of years depending on vocational school. The medical school has chemistry for two years (pharmacy technician), the Economic school has chemistry one year (economic technician) and the technical school (industrial-pharmaceutical technician) has chemistry for four years. The curriculum for all schools emphasizes knowing basic chemical concepts and facts regardless of the different duration of the chemistry education, the number of different chemistry courses, and the different number of classes per year. Looking into the curriculum of these different school profiles reveals the same main topics that provide students required knowledge. The number of classes for twhole chemistry education determined by the curriculum for each school and profile is provided in Table I.

TABLE I. Number of the chemistry classes per school

Type of school and selected profile	Number of the theoretical classes	Number of the practical classes
Gymnasium	288	74
Technical school	484	516
Medical school	134	0
Economic school	74	0

The total number of classes (theoretical and practical) determined by the curriculum for selected modules are 362 (Gymnasium), 1000 (Technical school), 134 (Medical school), and 74 (Economic school). A large number of the classes in Technical school is due to the fact that students in this school gain chemistry knowledge throughout several separate courses (General and Inorganic Chemistry, Organic chemistry, Analytical Chemistry, Physical Chemistry and Biochemistry). Other selected schools have one course through the years that covers all chemistry disciplines listed above.

Instrument / Design

The data were collected with the knowledge test administered to students in a paper form. The knowledge test contained 8 open-ended questions with a short answer. All the questions were based on the corresponding standards of achievements. The committee of experts (high school chemistry teachers and university chemistry teachers) who were not involved in its design confirmed the instrument's validity. Based on the evaluations, the revised items were held in the instrument. Questions from the knowledge test defined with corresponding standards of achievements are given in Table II.[22]

A set of questions covered by the instrument was chosen randomly from the curriculum with the intention to examine whether students know basic chemical concepts related with real life after they accomplish general chemistry education. The instrument was designed as a pilot version for providing insight into the current situation with students' chemical knowledge. The obtained results could serve as a motive for more extensive research.

TABLE II. Questions from the test with the respective standards of achievements

Question No.	Question	Standard of achievement
1.	In which human organ is the lowest pH value?	2.HE.1.1.5.
2.	At what temperature, ice melts, and inversely, water freezes to ice?	2.HE.1.1.2; 2.HE.1.2.3.
3.	Why is not good to squeeze the lemon into hot tea?	2.HE.1.3.2; 2.HE.1.4.1. 2.HE.1.4.2.
4.	Do sugar, milk, fruits, vegetables, bread contain the same carbohydrate?	2.HE.1.4.1; 2.HE.1.4.2.
5.	The test for drivers that measures the level of alcohol in the blood is based on which chemical reaction?	2.HE.1.3.3; 2.HE.1.3.4.
6.	Which compound provokes tingling after an ant’s sting?	2.HE.1.3.1; 2.HE.1.3.4.
7.	Which gas is more commonly known as laughing gas?	2.HE.1.2.3.
8.	We often hear that limescale does damage to various household appliances and that it comes from hard water. Which salts contribute most to water hardness?	2.HE.1.2.3.

The instrument covered almost all the chemistry disciplines: general chemistry (first two questions), inorganic chemistry (second and last two questions), organic chemistry (fifth, sixth and third questions) and biochemistry (fourth and third questions). Students should get the necessary knowledge and competencies to solve the test throughout their chemistry education at primary and secondary school. It is worth mentioning, that all high school students, included in this research, were in the final year of their chemistry education. All participants went through all the topics set in the instrument during the chemistry courses through their schooling. It was expected, based on the standards of achievement, that the majority would access a basic level of chemical knowledge, *i.e.* to recognize and connect chemical facts with daily life. Since chemical literacy is a multi-dimensional and complex term, it is difficult to assess all its aspects and components. The instrument was designed to measure acquired chemical knowledge for the end of general secondary chemical education, as well as knowing terms and facts from the chemistry domain, related to daily life. Without knowing basic chemical facts there is no functional chemical knowledge, as knowledge of these facts is a prerequisite for the existence of chemical literacy. The collected data were analysed both quantitatively and qualitatively with an emphasis on quantitative analysis, whereas the data analysis was carried out with several statistical tests (mean, standard deviation, Mann-Whitney test also called U-test).[35,36] Answers were summed and scored as correct, wrong and no answer. Descriptive statistics were reported in the percentages and the mean and standard deviation for the percentages were also given. The scoring scale, used to evaluate the level of students’ chemical knowledge, was constructed by the researchers and the responses to each question from the knowledge test were transcribed and scored. The scale was constructed and used to score and evaluate the students' chemical knowledge based on general standards of achievements for the end of secondary education.[22] Values of correct answers on the questions were scored from low (1), moderate (2) to high level (3) of chemical knowledge as indicated in Table III. The new scoring scale is designed for better insight into the students’ accomplishment of achievements on the knowledge test and better interpretation of the results. For primary school, it is specified that 80 % of students should achieve chemical knowledge at the basic level of standards of achievements.[37] As the standards of achievement for secondary school represent expanded knowledge, skills, and attitudes relative to those which are determined for primary school, it is expected that all high school students should achieve a basic level of standards of achievement.[38] All questions from the knowledge test were designed to be at a basic level by standards of achievements. The scale is determined by the number of correct answers, low level is less than 50 % correct answers, the moderate level implied 50-80 % of correct responses, whereas the high level is achieved with over 80 % of correct answers per question. Reaching a high level on the scale can be interpreted as satisfactory chemical knowledge on the basic level. The moderate level can be explicated as worrying, while the low level represents an alarming situation related to chemical knowledge. Expectations were that more than 80 % of students would reach a high level on the scoring scale.

TABLE III. Scoring scale for categorizing responses to questions

Level	Description of each category in interpretation responses
Low (1)	Students' chemical knowledge is low. Less than 50 % of correct answers per question. The situation is alarmingly worrying.
Moderate (2)	Students' chemical knowledge is moderate. Students' correct answers are between 50-80 % per question. The situation is worrying.
High (3)	Students' chemical knowledge is high. More than 80 % of correct answers per question. The situation is satisfactory.

RESULTS AND DISCUSSION

The data collected with the knowledge test are presented in the Table IV. Results (number of wrong, correct, and no answers) are given in percentages and the number of respondents is given in parentheses.

TABLE IV. Distribution of answers on the knowledge test

Question No. (Table II)	Contribution, %[a]		
	Correct answers	Wrong answers	Without answers
1	70.71 (268)	15.83 (60)	13.46 (51)
2	31.66 (120)	62.80 (238)	5.54 (21)
3	65.70 (249)	15.30 (58)	19.00 (72)
4	78.90 (299)	14.51 (55)	6.60 (25)
5	27.70 (105)	16.62 (63)	55.67 (211)
6	58.05 (220)	11.61 (44)	30.34 (115)
7	46.96 (178)	40.37 (153)	12.66 (48)
8	46.17 (175)	19.26 (73)	34.56 (131)

[a]number of respondents are given in the parentheses

Transcribed to a researchers' scale, respondents are on the transition of two levels, low and moderate. Students showed a moderate level of chemical knowledge (50-80 % correct answers) on four questions (Question No. 1, 3, 4 and 6) and low level (<50 % correct answers) on the same number of questions (Question No. 2, 5, 7 and 8) toward scale score, but no one achieved a high level of knowledge. Based on these results, the students do not reach the expected level of basic chemical knowledge and the situation in schools can be interpreted as not satisfactory.

The question with the most correct answers is the fourth question (78 %), while the question with the lowest number of correct answers is the fifth question (27.7 %). It is important to pay attention to a low level of chemical knowledge of the students related to the second question where the number of correct answers was only 31.66 %. Based on these results, the students did not achieve a sufficient level of basic chemical knowledge, as expected by standards of achievement.[37,38]

According to the scoring scale and students' accomplishments on the individual questions (1, 3, 4 and 6), students know on a moderate level: acid-base properties of some body fluids and substances from real life (2.HE.1.1.5.); the role and presence of biologically important compounds as well as their physical properties and structure (2.HE.1.3.2.; 2.HE.1.4.1. and 2.HE.1.4.2.); structure, physical properties of carbohydrates (2.HE.1.4.1. and 2.HE.1.4.2.); trivial names of organic compounds and corresponding names according to IUPAC nomenclature (2.HE.1.3.1.), physical and chemical properties of organic compounds, and also their importance in everyday life (2.HE.1.3.4.). More precisely, students know on the moderate level which organ in the human organism is with the lowest pH value (stomach); the physical properties of vitamin C, *i.e.* they know what happens with vitamin C at high temperatures (decomposition); formic acid provokes tingling after an ant's sting and that sugar, milk, fruits, vegetables, and bread do not contain the same carbohydrate.

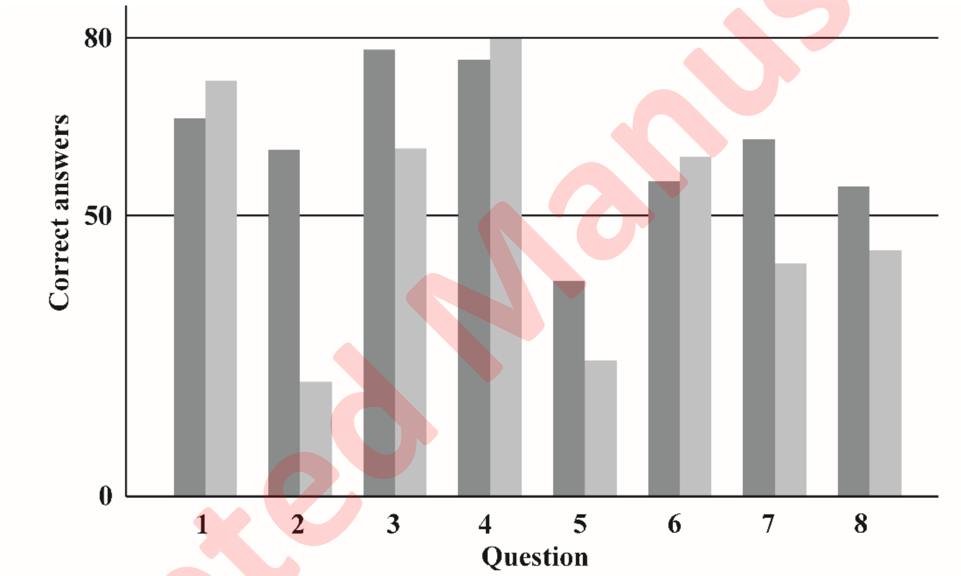
Students' responses on the 2nd, 5th, 7th, and 8th questions disclose a low level of knowledge on the researchers' scale for the selected chemical facts: the physical and chemical properties of substances that they encounter in daily life (2.HE.1.1.2.; 2.HE.1.2.3.); chemical properties and some of the most significant reactions of organic compounds (2.HE.1.3.3. and 2.HE.1.3.4.) and the most important inorganic compounds as well their applicability (2.HE.1.2.3.). Accurately, students were expected to know at what temperature ice melts and water freezes; oxidation reaction of alcohol and reduction reaction of dichromate is that one on which is based test that measures the level of alcohol in the blood of drivers; nitrous oxide is laughing gas and that the salts of divalent metal cations contribute the most to the water hardness (Ca^{2+}; Mg^{2+}, *etc.).*

The assessment of students' chemical knowledge revealed that only a small percentage of them know basic chemical facts related to real life. The problem may be that the newly acquired knowledge is not well assimilated, and thus, does not contribute to the students' ability to meaningfully comprehend basic chemical concepts. The results also indicate many misinterpretations and misconceptions caused by mechanical learning. For example, helium was mentioned as the laughing gas instead of dinitrogen oxide or histamine, not formic acid, as a substance that causes tingling. Also, the frequent wrong answer was that ice melts at 4 °C and inversely, water becomes ice, probably because students know that this temperature is characteristic for water (on 4°C water has maximum density).

Fig. 1 presents the students' correct answers to questions from the knowledge per school.

The present researchers expected a non-significant difference in responses between students from two types of schools, firstly, because questions were constructed on the basic level of chemical knowledge, and secondly, because the content and curriculum from both schools have the same goal, chemical literacy, and knowledge retention.

Fig. 1. Distribution of respondents' correct answers on questions per school; light grey -



gymnasium, dark grey - vocational school

The mean value of the correct answers of Gymnasium students is 50.00 with a standard deviation of 20.43, whereas this value for students from Vocational school is 61.24 with a standard deviation of 12.12. Based on these values, it may be concluded that students from the vocational school give more correct answers per question with smaller deviation from the mean, and barely cross the moderate level of chemical knowledge towards researchers' scale score. On the other hand, students from Gymnasium show oscillations in the number of correct answers per question, and do not cross the moderate level. U-test, that was carried out shows a significant difference with a *p*-value of 0.44 (p > 0.05; z = ±0.77). It cannot be known what happened in the individual classes through students' education, so, the difference may be caused by the individual characteristics of both teachers and students and the quality of the teaching process.

The obtained results clearly show disagreement with the goals defined in curriculum which is based on applicable knowledge. A large number of wrong answers suggest that the learning process in Serbia’s high schools is still grounded only on the reproduction of the content. Without the opportunity to understand and link content with real life, students will develop misinterpretations and misconceptions, so it is for expecting that students would not be able to apply their knowledge.[39]

Regarding this finding, developing new teaching forms could impact the functionality of students' knowledge and it is also a call for chemistry teachers to provide an appropriate and conducive learning environment during the learning process. The context of chemistry toward daily life situations should provide students the possibility to improve their literacy skills.[40,41] Context-based learning with engaging all students during the learning process makes chemistry more relevant and relative to the students.[42] Such approach leads students to make links between real life and chemistry, with context that can be an environmental issue, an everyday life problem, or an industrial process.[43] Also, it is required to enhance the students’ intrinsic motivation. Without this, students will continue to form knowledge with limited understanding based only on memorized facts.

CONCLUSION

For a long time, literacy does not mean just being able to read and write. No matter whether your work is connected directly or indirectly with chemistry, or you compete in a quiz, read some newspaper article, or buy a cosmetic product, you should have a basic level of chemical knowledge or, in other words, be chemical literate. Chemical literacy is a target in major reforms in science education today and it is conceptualized as a main goal. With that goal achieved, the school will provide people with sufficient and functional knowledge and the ability for solving real life problems.

The results obtained in this paper have highlighted that knowing basic chemical facts (as a prerequisite for chemistry literacy) among students remains low. It is worrying that the students do not know at what temperature ice melts *i.e.* water freezes to ice, and also, other similar chemical concepts tested with the instrument. The ignorance of the basic chemical concepts brought students to an unsatisfactory level of basic chemical knowledge. The achieved level of basic chemical knowledge is not sufficient for connecting the acquired knowledge with real life situations, and thus for the application of chemical concepts in daily life. Therefore, students mostly do not have the prerequisite for chemical literacy. Based on the standards of achievements, eexpectations were that more than 80 % of students would reach a high level on our scoring scale. The results reveal that the situation about students’ chemical knowledge is not satisfactory, none of the question reached a high level of the scoring scale. The authors had believed that there will be no significant difference in responses between students from different school profiles. Based on the results, students from the Vocational school gave more correct answers per question than students from Gymnasium. This result can trigger new research with an aim to confirm this difference and to analyse the reasons. The findings reflect that there still exists a need for developing learning activities throughout chemistry education to provide a chance for students to use their knowledge in real life situations.

Our results were collected before the SARS-CoV-2 pandemic, in 2018. The obtained results could serve as a motive for broader research on students' chemical literacy. A similar study is planned, after the pandemic is put under control, to examine the impact of simultaneously, non-simultaneously, and blended E-learning on students' knowledge required for reaching even a basic level of chemical literacy.

Acknowledgements: This work was supported by the Serbian Ministry of Education, Science and Technological Development (Agreement Nos. 451-03-68/2022-14/200122 and 451-03-01330/2020-14/2787).

ИЗВОД

ДА ЛИ УЧЕНИЦИ СРЕДЊИХ ШКОЛА У СРБИЈИ ИМАЈУ ФУНКЦИОНАЛНО ХЕМИЈСКО ЗНАЊЕ?

ФИЛИП СТАШЕВИЋ[1], НАСТА МИЛЕТИЋ[2], ЈЕЛЕНА ЂУРЂЕВИЋ НИКОЛИЋ[1] и ИВАН ГУТМАН[1]

[1]*Универзитет у Крагујевцу, Природно-математички факултет, Радоја Домановића 12, 34000 Крагујевац, Србија и* [2]*Гимназија Косовска Митровица, Лоле Рибара 29, 38220 Косовска Митровица, Србија*

Већ дужи временски период бити писмен не подразумева само способност писања и читања. Хемијска писменост, као део научне писмености, представља употребу знања, вештина и ставова у решавању различитих друштвених изазова. Свест друштва о значају хемије, хемијску писменост уводи на листу главних циљева образовања и васпитања. Да би испитали ниво хемијског знања и ниво познавања основних хемијских чињеница, што је предуслов за хемијску писменост, средњошколаца (N=379) осмишљен је упитник и скала за евалуацију постигнућа. Приказани резултати су у супротности очекивањима, тј. нису остварени захтеви дефинисани стандардима постигнућа на основном нивоу. Мали број тачних одговора указује да испитивани узорак ученика не поседује задовољавајући ниво хемијског знања, што наводи на потребу за развијањем нових, напреднијих метода у настави хемије.

(Примљено 26. новембра 2021; ревидирано 21 новембра 2022; прихваћено 22. новембра 2022.)

REFERENCES

1. B. V. Street, *Literacy in Theory and Practice*, Cambridge University Press, New York, USA, 1984
2. P. Turiman, J. Omar, A. Mohd Daud, K. Osman, *Procedia Soc. Behav. Sci*. **59** (2012) 110 (https://doi.org/10.1016/j.sbspro.2012.09.253)
3. L. Verhoeven, *Functional Literacy*, in: *Encyclopedia of Language and Education. Encyclopedia of Language and Education vol 2,* V. Edwards, D. Corson, Eds., Springer, Dordrecht, Netherlands, 1997 (https://doi.org/10.1007/978-94-011-4540-4_14)
4. N. Feinstein, *Sci. Ed.* **95** (2011) 168 (https://doi.org/10.1002/sce.20414)

5. S. Livingstone, *Commun. Rev.* **7** (2010) 3 (https://doi.org/10.1080/10714420490280152)
6. D. Bawden, *Origins and Concepts of Digital Literacy*, in: Digital Literacies: Concepts, Policies and Practices, C. Lankshear, M. Knobel, Ed(s)., Peter Lang, New York, USA, 2008 (ISBN: 1433101696)
7. C. A. Cassel, C. C. Lo, *Polit. Behav.* **19** (1997) 317 (https://doi.org/10.1023/A:1024895721905)
8. R. C. Laugksch, *Sci. Ed.* **84** (2000) 71 (https://doi.org/10.1002/(SICI)1098-237X(200001)84:1<71::AID-SCE6>3.0.CO;2-C)
9. W. Graber, P. Nentwig, H. Becker, E. Sumfleth, A. Pitton, K. Wollweber, D. Jorde, *Scientific Literacy: From Theory to Practice*, in: *Research in Science Education - Past, Present, and Future*, H. Behrendt, Ed(s)., Springer, Dordrecht, Netherlands, (2001) (https://doi.org/10.1007/0-306-47639-8_6)
10. S. Avargil, O. Herscovitz, Y. J. Dori, *Think. Skills Creat.* **10** (2013) 189 (https://doi.org/10.1016/j.tsc.2013.07.008)
11. Y. Shwartz, R. Ben-Zvi, A. Hofstein, *J. Chem. Educ.* **83** (2006) 1557 (https://doi.org/10.1021/ed083p1557)
12. R. M. Hazen, J. S. Trefil, *J. Chem. Educ.* **68** (1991) 392 (https://doi.org/10.1021/ed068p392)
13. R. W. Missen, W. R. Smith, *J. Chem. Educ.* **66** (1989) 217 (https://doi.org/10.1021/ed066p217)
14. Y. Shwartz, R. Ben-Zvi, A. Hofstein, *Chem. Educ. Res. Pract.* **7** (2006) 203 (https://doi.org/10.1039/B6RP90011A)
15. M. K. Serry, C. McDonnell, *Chem. Educ. Res. Pract.* **14** (2013) 227 (https://doi.org/10.1039/C3RP90006A)
16. Z. Kohen, O. Herscovitz, Y. J. Dori, *Chem. Educ. Res. Pract.* **21** (2020) 250 (https://doi.org/10.1039/c9rp00134d)
17. P. E. Childs, S. M. Hayes, A. O'dwyer, *Chemistry and Everyday Life: Relating Secondary School Chemistry to the Current and Future Lives of Students*. in: *Relevant Chemistry Education*. I. Eilks, A. Hofstein, Ed(s)., SensePublishers, Rotterdam, Netherland, (2015) (https://doi.org/10.1007/978-94-6300-175-5_3)
18. J. C. Besley, A. Dudo, M. Storksdieck, *J. Res. Sci. Teach.* **52** (2015) 199 (https://doi.org/10.1002/tea.21186)
19. T. Brown, H. E. LeMay, B. E. Bursten, *Chemistry the Central Science*, 8th edition, Prentice Hall, New Jersey, United States, 2015 (ISBN: 0130103101)
20. P. Karvankova, D. Popjakova, *Int. J. Sci. Educ.* **40** (2018) 702 (https://doi.org/10.1080/09500693.2018.1442598)
21. *Curriculum for high schools, vocational schools and adult education*, Official Gazette, Belgrade, Serbia, https://zuov.gov.rs/zakoni-i-pravilnici (9. 3. 2022.) (in Serbian)
22. *General standards of achievement for the end of general secondary education and upbringing and secondary vocational education and education in the field of general education subjects for the subject - Chemistry*, Institute for the Evaluation of the Quality of Education, Belgrade, Serbia, 2013 (in Serbian) (https://ceo.edu.rs/стандарди-у-образовању) (8. 3. 2022)
23. D. Trivić, *Hemijski Pregled* **51** (2010) 148 (in Serbian)
24. K. Eriksson, O. Helenius, A. Ryve, *Instr. Sci.* **47** (2019) 1 (https://doi.org/10.1007/s11251-018-9473-1)
25. National Center for Education Statistics (NCES), *Trends in International Mathematics and Science Study* (TIMSS), http://nces.ed.gov/TIMSS/ (13. 9. 2021.)

26. M. O. Martin, I. V. S. Mullis, P. Foy, G. M. Stanco, TIMSS 2011 International Results in Science, TIMSS & PIRLS International Study Center, Boston College, Chestnut Hill, MA, 2012
27. M. O. Martin, I. V. S. Mullis, P. Foy, M. Hooper, TIMSS 2015 International Results in Science, TIMSS & PIRLS International Study Center, Boston College, Chestnut Hill, MA, 2016
28. I. Đerić, N. Gutvajn, S. Jošić, N. Ševa, *National report TIMSS 2019 in Serbia*, Institute for pedagogical investigations, Belgrade, Serbia, 2020 (ISBN 978-86-7447-153-1) (in Serbian)
29. V. F. Savec, B. Urankar, M. Aksela, I. Devetak, *J. Serb. Chem. Soc.* **82** (2017) 1193 (https://doi.org/10.2298/JSC161221083S)
30. P. J. Fensham, W. Harlen, *Int. J. Sci. Educ.* **21** (1999) 755 (https://doi.org/10.1080/095006999290417)
31. W. Harlen, *Stud. Sci. Educ.* **36** (2011) 79 (https://doi.org/10.1080/03057260108560168)
32. Organization for Economic Co-operation and Development (OECD-PISA), *Assessment of scientific literacy in the OECD* / Pisa project, http://www.pisa.oecd.org/ (13.9.2021.)
33. J. Korolija, S. Rajić, M. Tošić, Lj. Mandić, *J. Serb. Chem. Soc.* **80** (2015) 1567 (https://doi.org/10.2298/JSC150522072K)
34. M. Videnović, G. Čaprić, *PISA 2018 Report for the Republic Serbia*, Ministry of Education, Science and Technological Development of the Republic of Serbia, Belgrade, Serbia, 2020 (in Serbian)
35. E. McCrum-Gardner, *Br. J. Oral. Maxillofac Surg.* 46 (2008) 38 (https://doi.org/10.1016/j.bjoms.2007.09.002)
36. H. W. Kruskal, A. W. Wallis, *J. Am. Stat. Assoc*. **47** (1952) 583 (https://doi.org/10.2307/2280779)
37. D. Trivić, R. Jankov, M. Ranđelović, V. Vukotić, M. Marković, R. Kovačević, M. Nikolić, *Educational standards for the end of compulsory education for the subject - chemistry*, Ministry of Education, Science and Technological Development of the Republic of Serbia, Belgrade, Serbia, 2010 (ISBN 978-86-86715-22-7) (in Serbian)
38. *General standards of achievements for the end of general secondary and secondary vocational education and upbringing in the part of general education subjects for the subject - Chemistry*, Handbook for teachers, Institute for the Evaluation of the Quality of Education and Upbringing, Belgrade, Serbia, 2015 (ISBN 978-86-86715-55-5) (in Serbian)
39. T. Hrin, D. Milenković, M. Segedinac, *Chem. Educ. Res. Pract.* **19 (**2018) 305 (https://doi.org/10.1039/c7rp00162b)
40. J. Bennett, J. Holman, *Context-Based Approaches to the Teaching of Chemistry: What are They and What Are Their Effects?* in: *Chemical Education: Towards Research-based Practice. Science & Technology Education Library vol. 17*, J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust, J. H. Van Driel, Ed(s), Springer, Dordrecht, Netherlands (2002) (https://doi.org/10.1007/0-306-47977-X_8)
41. Y. J. Dori, S. Avargil, Z. Kohen, L. Saar, *Int. J. Sci. Educ*. **40** (2018) 1198 (https://doi.org/10.1080/09500693.2018.1470351)
42. J. K. Gilbert, *Int. J. Sci. Educ.* **28** (2006) 957 (https://doi.org/10.1080/09500690600702470)
43. J. P. Gutwill-Wise, *J. Chem. Educ.* **78** (2001) 684 (https://doi.org/10.1021/ed078p684).