Scientific paper

The Accuracy of Macro–Submicro–Symbolic Language of Future Chemistry Teachers

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Abstract

The present study is focused on the examination of language accuracy of future chemistry teachers in the macro–submicro–symbolic domain. Since the knowledge at the submicroscopic level is crucial for the understanding of chemical concepts and ideas, the aim of this study was to examine the accuracy of the language of future chemistry teachers while delivering chemical contents at this level. Within this objective, it was examined whether future chemistry teachers make a distinction between submicroscopic and macroscopic levels, as well as between submicroscopic and symbolic levels in their speech. Using qualitative methods of analysis, it was found that the majority of surveyed future chemistry teachers did not have the expected and necessary language accuracy within the examined domain. Most worrying were the attitudes of future chemistry teachers, who perceived the accurate expressions in the macro–submicro–symbolic domain as a redundant complication rather than a necessity.

Keywords: Future chemistry teachers; language accuracy; micro-submicro-symbolic language

1. Introduction

The concept of three levels of chemical representation, or the so-called "triplet relationship"[1] has been attracting the attention of a large number of researchers in the field of chemical education for many years. Although this notion was first mentioned in 1982 it still seems to be very influential and widespread among researchers.[2] From the basic idea that chemical contents can be taught on three levels, commonly called macroscopic (sensory accessible properties of substance), submicroscopic (particulate level) and symbolic (symbols, formulae, equations), multiple lines of research have been established over time. Nonetheless, most attention has been paid to the problems and misconceptions that occur as a result of misinterpretations regarding the submicroscopic level.[3–5] Along with the fact that this level is the most abstract one and therefore the most difficult to master, some researchers have suggested that there is an additional issue that further fosters these difficulties, and that is the imprecise use of language.[6,7] Namely, teachers, textbook writers or scientists are prone to use language in a way that does not maintain the necessary distinction between macroscopic and submicroscopic levels. Thus, it is quite common to hear teachers saying e.g. that ammonia consists of nitrogen and hydrogen, that stearic acid has a long chain of C-atoms or that oxygen has a double bond, when in fact they referring to particles of these substances. However, students commonly lack the skill to shift between levels, which further complicates the already heavy and abstract submicroscopic concepts. The same can be said of the writers of school textbooks, who have a fairly inattentive approach to this issue. For example, in textbooks approved by the Ministry of Education of the Republic of Serbia for primary school chemistry, it is possible to find statements such as the following:

Each period, except the first, ends with the element that has 8 electrons in the highest energy level;[8] electronegativity is the ability of a chemical element to attract the electron pair;[9] carboxylic acids which have a higher number of carbon atoms are referred to as a higher fatty acid;[10] benzene contains six carbon and six hydrogen atoms.[11]

The above examples clearly show the use of blurred language concerning macroscopic and submicroscopic. Furthermore, researchers have also pointed out the interference between macroscopic and submicroscopic levels in some presentations of the Periodic table of elements,[12] as some of the data provided, refer to submicroscopic particles (e.g. electron configuration, atomic and mass number), while some of them refer to elementary substances (e.g. density, state of matter) which leads to confusion among students.

Such inconsistencies, which are likely the result of teachers' or textbook writers' carelessness, may have some severe consequences on students' meaningful understanding. Namely, such approach could be one of the possible causes of the formation of a well-known and scrutinized misconception of transmission of substance macroscopic properties to its submicroscopic particles. Thus, it is not surprising that students believe that molecules of solids are hard unlike molecules of liquids and gasses,[13] that molecules of water can be hot and cold, that molecules of naphthalene have an odour[14] or that sulphur atoms are coloured yellow[15] given that the macro-submicro terms are used quite often interchangeably during classes.

Besides this flimsy language between macro and submicro domains, inaccurate language can also appear between submicro and symbolic domains. Namely, the symbolic models may appear to be the reality for many students. Chittleborough and Treagust stated that teachers insufficiently emphasize the representational nature of the formulas, saying, for example that CH_4 is methane, instead that it represents the composition of a methane molecule.[16] Kleinman, Griffin, and Kerner reported about a student who believed that bromobenzene has no plane of symmetry since B ≠ r, which is an obvious example of the fact that some students firmly adhere representations, instead of submicroscopic reality.[17] Furthermore, favouring symbolic visualizations over underlying submicroscopic concepts is commonly present when dealing with chemical equations.[18] It means that student may become very adept at manipulating a chemical equation, without its proper reasoning.

There is an interesting view that the language itself could act as a greater barrier for learning than contents of natural sciences.[19] Namely, the peculiarity of chemistry by which it differs from other natural sciences is the developed system of scientific communication – chemical language. It often happens that words of chemical language are used in everyday life, but with different meaning, which can create difficulties for students. Confusion arises when teachers in explaining some chemical concepts use words that are also used in everyday life (e.g. pure, reduction, etc.), assuming that students will understand them in a chemical way.[20] Sometimes in chemistry, even one word can have several meanings (e.g. *neutral* oxide, pH-*neutral*, *neutral* atom), which additionally frustrates students. Studies show that accurate and consistent use of chemical language, especially in describing the substance at the submicroscopic level enhances the students' ability to interpret concepts.[15]

Accordingly, it is important that teachers are aware of the significance of accurate and precise expression, which necessarily includes the precise expression in the macro–submicro–symbolic domain. Otherwise, the imprecise use of language, though often unintended, can create barriers to learning.

2. Methodology

2. 1. Aim of Research

Assuming that imprecise and inconsistent use of chemical language in the macro–submicro–symbolic domain by teachers can represent the basis for the formation of biases and misconceptions, the main objective of this study was to examine the precision of future chemistry teachers' language within macro–submicro–symbolic domain. Within this goal, two research tasks have been set:

T1: To determine whether future chemistry teachers make a clear distinction between macroscopic and submicroscopic levels in their explanations.

T2: To determine whether future chemistry teachers make a clear distinction between submicroscopic reality and symbolic representations in their explanations.

2. 2. Context of the Study

In the Republic of Serbia, there are two basic university programs for education of chemistry teachers – bottom-up and concurrent model. At the faculties with a bottom-up model, students opt for teaching programme at the beginning of their studies. At the faculties with a concurrent model, such as the Faculty of Sciences (University of Novi Sad) where the research was conducted, students study compulsory chemistry courses, and to be profiled in the direction of teaching chemistry, students have to acquire a regulated number of credits in educational courses and compulsory school practice, during the studies through elective courses. Within school practice courses, students are required to undergo two main parts: (1) observations of classes performed by licensed mentor-practitioner, without participation in the teaching and (2) teaching under supervision of licensed mentor-practitioner.

At the Department of Chemistry, Biochemistry and Environmental Protection, Faculty of Sciences, there are two courses of school practice: (1) School practice I (8^{th} semester; primary school teaching: 7^{th} and 8^{th} grade) and (2) School practice II (10^{th} semester; secondary school teaching: 9–12^{th} grade). Within the first stage of the School practice (both I and II), students have to observe 25 classes (18.75 hours) performed by experienced mentor-practitioner. In the next stage, students are required to independently hold at least 5 classes under supervision of mentor-practitioner. Additionally, students are required to attend weekly coaching lessons.

2. 3. Participants and Setting

Students who enrolled in the School practice I course at the Department of Chemistry, Biochemistry and Environmental Protection, Faculty of Sciences, Novi Sad in 2014/15 academic year were participants of this study (N = 16). All of them were female students majoring in chemistry teaching in their fourth and final year of their Bachelor degree. Most of the subjects had completed obligatory subject matter courses before selecting the School practice I course. In addition, the majority of them have taken following educational courses as well: Pedagogy, Psychology, Introduction to Teaching Profession, Methods of Teaching Chemistry I and II and Modern Educational Technology in Teaching Chemistry.

The research was conducted in three public, urban schools located in the municipality of Novi Sad, Province of Vojvodina wherein students observed and held classes. Mentors-practitioners were three licensed chemistry teachers (one from each school) who have at least 5 years of work experience in primary school teaching and who have been achieving excellent educational results in their teaching practice.

Prior to conducting the survey, all participants were informed that the lessons will be voice recorded and that the results will be used for research purposes. After the research procedure was explained, all the students gave their consent to voluntarily participate in the research.

2. 4. Study Design

To obtain data, qualitative research methodology was used. Namely, two authors of this paper (university staff) have been present during all the classes that were held independently by students (a total of 80 classes, 60 hours) and marked the errors encountered. The role of university staff was both advisory and assessment similar to other research studies.[21] In addition, all classes were voice recorded. Since there is no uniform protocol for monitoring school practice, which is in accordance with competency standards for the profession of teachers and their professional development in the Republic of Serbia, in this study we used an internal protocol developed by the authors of this paper. It involved consideration of the following points in line with the mentioned standards: content knowledge, pedagogical knowledge, connection of new information to prior knowledge, correlations to contents of other subjects, use of everyday life examples, classroom management, and literacy. In addition, special attention was paid to monitoring the precision of language in the macroscopic, submicroscopic and symbolic domain, which was the main topic of this study. In addition to observations, after each class, in the five-minute break between classes, the authors conducted brief interviews with the future chemistry teachers to determine their awareness of inaccurate use of language in the macro–submicro–symbolic domain, during teaching.

All teaching topics covered in this study are shown in Table 1.

3. Results and Discussion

3. 1. Macro–Submicro Inaccuracies

Within data interpretation, the field notes as well as voice recordings were carefully analysed and categorised according to two defined research questions.

Since the first task was related to the determination of language accuracy in macro–submicro domain, the first part of this section will be devoted to the analysis of the most frequent linguistic imprecisions that were noticed during the monitoring future teachers' classes. The list of imprecise and unclear statements has been extracted and summarized in Table 2. It is important to note that in addition to the statements specified in Table 2, similar statements have also been recorded, however, to avoid redundant repetition they are not included in the Table 2.

Statements of the type I (Imprecise expression of the particle type; S1–S4 in Table 2) were recorded during the various teaching topics and were constantly repeated by

Table 1. Topics Covered During Data Collection

Grade	Teaching unit	Type of class*
VII	Solubility of substances and percentage composition of the solution	PNMT
VII	Solubility of substances and percentage composition of the solution	R
VII	Water	PNMT
VII	Chemical reactions. Analysis and synthesis	PNMT
VII	Chemical equations	R
VII	The law of conservation of mass	PNMT
VIII	Oxygen containing organic compounds	R
VIII	Physical and chemical properties of carboxylic acids	PNMT
VIII	Physical and chemical properties of carboxylic acids	R
VIII	Esters	PNMT
VIII	Carbohydrates, monosaccharides	PNMT
VIII	Disaccharides and polysaccharides	PNMT
VIII	Fats and oils	PNMT
VIII	Amino acids and proteins	PNMT
VIII	Vitamins	PNMT

*PNMT (Processing new teaching material); R (Revising)

Table 2. List of Imprecise Statements in relation to Macro-Submicro Level

Type	No.	Statement/Question
I	S1	Molecules of sodium chloride
I	S2	On the left side, we have three molecules of sodium hydroxide
I	S3	The molecules of soap can remove the stain
I	S4	On the third carbon atom, OH molecule is located on the left side
II	S5	Which atoms have that sugar?
II	S6	From one molecule of sucrose, glucose and fructose can be obtained
II	S7	Water is composed of two hydrogen atoms and one atom of oxygen
II	S8	The oligosaccharides contain 2–10 monosaccharides
II	S9	When equalizing this equation, we should first counter the number of oxygen
II	S10	How many hydrogens are there on the left side?
III	S11	Compounds with a polar covalent bond can be dissolved in water
III	S12	How are oxygen and hydrogen connected in water?
IV	S13	Tap water is a pure water

the majority of future chemistry teachers. Listening to the voice recordings, it was found that future chemistry teachers often used the expression "molecule" to represent main particles which build ionic compounds. Besides sentence such as: "there are molecules of sodium chloride in this solution", analogous sentences and questions were also recorded, such as: "on the left side, we have three molecules of sodium hydroxide", "molecules of soap can remove the stain", "what do we call a molecule of copper(II) sulphate", "if we want to obtain a molecule of iron(II) sulphide, we need 7 g of iron, and 4 g of sulphur" etc. Furthermore, while writing formula of glucose molecule, one future chemistry teacher said: "on the third carbon atom, OH molecule is located on the left side".

Reviewing the literature, we found information on the widespread school-made misconception among students, that the main particles that build the substance sodium chloride are neutral molecules,[22–25] then $CaCl_2$ molecules are present in water which contains calcium chloride,[26] or students write balanced equations of reactions in which the ionic compounds dissolve as neutral atoms or molecules.[27] In the case where students have acquired this misconception, the inattentive speech of a teacher can additionally enhance it.

Statements of the type II (Neglecting particle terms and prevalent use of macroscopic terms; S5–S10 in Table 2) were recorded among the majority of future chemistry teachers. Based on the above examples it can be noted that future chemistry teachers' expressions in terms of particles are quite imprecise, and very often replaced by analogous macroscopic terms. However, such statements may confuse students who are at the very beginning of their chemical education and who have yet to establish a flexible system of knowledge with firmly incorporated fundamental chemical concepts. Due to the aforementioned statements, students may conclude that the main building blocks of sugars are free atoms ("which atoms have that sugar"), that water is a mixture composed of hydrogen and oxygen ("water is composed of two hydrogen atoms and one atom of oxygen") or may neglect the fact that small amounts of some substance contain an enormous number of particles ("from one molecule of sucrose glucose and fructose can be obtained"; "fructose consist of six carbon atoms, ketone carbonyl group and five hydroxyl groups"; "carboxylic acids which have 4–7 carbon atoms are malodorous"). The statements such as: "when equalizing this equation, we should first count the number of oxygen" and "how many hydrogens are there on the left side?", which are related to chemical equations, should be particularly stated. Namely, it is observed that future chemistry teachers rarely use particulate terms while balancing equations, replacing them with terms such as "one hydrogen on the left side, two oxygens on the right side" and the like.

Within type III (Chemical bond as a feature of elementary substance), two statements were noted (S11 and S12 in Table 2). Namely, a future chemistry teacher asked: "how are oxygen and hydrogen connected in water", which can make students think that water is made of chemically bonded molecules of hydrogen and molecules of oxygen rather than water molecules. Another such case arises from the statement: "compounds with polar covalent bonds can be dissolved in water". Likewise, students can conclude that a polar covalent bond occurs between the particles of a compound, and not within the particle.

One statement of the type IV (Mixing chemical terms with everyday life terms; S13 in Table 2: Tap water is a pure water) has been observed in the case of four future teachers during the teaching topic "Water". Namely, comparing the prepared samples of tap water and water from a local canal, a future teacher used the term "pure water" instead of clear water without considering the fact that chemically pure water has a different meaning. As already mentioned, one of the problems, frequently encountered during teaching of chemistry, is that some words used in everyday life can sometimes be used in chemistry but with a different meaning. In the presented case, the future teacher was thinking about physically pure water i.e. water that is not contaminated by other substances which may affect its physical appearance. However, the expression pure water in chemical and theoretical sense would mean that the tap water consists of water molecules only, which cannot be concluded merely on the basis of its physical appearance. This led to confusion, as in the final part of the class, during the revision, some students stated tap water as an example of a pure substance.

Taber stated that chemistry teachers use the term pure substance as a technical term thinking of the composition of the substance at the submicroscopic level, while at the same time students are more focused on the external appearance of a substance, which leads to common problems in teaching practice.[28] In this case, it can be noted that the future teacher was also thinking about the external appearance of substance, without considering the possible biases that go along with that term.

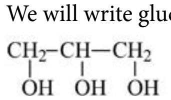
After interviews with the future chemistry teachers, it was noticed that they do not pay attention to the precise language at the submicroscopic level. Moreover, they do not believe that it could have an impact on creating confusion among students. Some future chemistry teachers even after the interview and the reflection on differences between the two modes of expressions did not consider precise language as required, but rather as complicated. Similarly, Gilbert, and Treagust stated that some authors believe that the introduction of additional submicroscopic terms, with a view to precise language, unnecessarily complicates sentences and does not contribute to the removal of ambiguities among students.[1] Worryingly, some future chemistry teachers in this study could not even comprehend the difference between the two modes of expressions.

3. 2. Submicro–Symbolic Inaccuracies

In this section, we present a table with noted inaccuracies within the submicro-symbolic domain. Recorded inaccurate statements (S1–S6) as well as graphical representations (G1–G2) are summarised and given in Table 3.

The statement of the type I (Reasoning at symbolic level; S1 in Table 3) was recorded during the teaching topic Esters. Namely, one future chemistry teacher explained the esterification reaction in the following manner: "In the esterification reaction, ester and water are formed. We know that the water is made up of two hydrogen atoms and one oxygen atom. Therefore, we have OH (showing on the condensed structural formula of ethanol), and H (showing on the condensed structural formula of ethanoic acid) and we get water, and all that remains combines into a new compound. So, on the left side we will have CH_3CH_2, and on the right side CH_3COO and one free bond which we can use to connect the left and right side of the compound". In addition to the inaccurate expression at submicroscopic level and content knowledge flaws (probably substituting esterification with neutralisation reaction), the described situation clearly illustrates an example of reasoning at the symbolic level. Namely, the future teacher has poorly developed concepts of chemical bond and chemical reaction. Reviewing the literature, we came across various misconceptions regarding chemical bond and bonding. This area of research has proved to be one of the most studied one in the last several decades.[29–33] Researchers, acting in this area, identified some interesting misconceptions, however, this study revealed another interesting misconception. Namely, the future chemistry teacher conceived chemical bond as a tangible strong connection (stick) that can be transferred from one place to another and used to connect the atoms or atomic groups, similar to molecular models. On the other hand, this future chemistry teacher understood the chemical equation as a simple combination of atoms without considering the mechanism of chemical reactions. This is not surprising, given that many researchers in literature reported the students' ability to write and equate chemical equations without proper submicroscopic reasoning.[18]

Table 3. List of Imprecise Statements in relation to Submicro-Symbolic Level

Type	No.	Statement/Graphical representation
I	S1	In the esterification reaction, ester and water are formed. We know that the water is made up of two hydrogen atoms and one oxygen atom. Therefore, we have OH (showing on the condensed structural formula of ethanol), and H (showing on the condensed structural formula of ethanoic acid) and we get water, and all that remains combines in a new compound
II	S2	We will write a reaction of photosynthesis
II	S3	Is there anyone who knows how to balance this reaction?
II	S4	On the left side of the reaction there are ethanol and acetic acid, while on the right side there are ester and water
II	S5	Substance that undergoes chemical change is written on the left side of the reaction
II	S6	We will write glucose
III	G1	
III	G2	$C_{12}H_{22}O_{11} + H_2O \overset{H^+}{\longleftrightarrow} C_6H_{12}O_6 + C_6H_{12}O_6$

Within type II (Mixing symbolic terms and submicroscopic reality) five statements were recorded (S2–S6 in Table 3). Namely, by observing the lessons of future chemistry teachers, we were able to notice that future teachers commonly do not make a distinction between reaction and the chemical equation as its representation in their speech; between a compound and its representation – formula, or between an atom of an element and its representation – symbol. Therefore, we were able to record some very imprecise constructions such as: reaction of photosynthesis, left side of the reaction, we will write glucose, and others listed in Table 3. However, since chemistry is a subject which emphasizes precision and accuracy, the precise use of language also implies.[34]

The third type of observed inaccuracies was related to imprecise writing of chemical formulas and equations. In the Table 3 we gave two examples, one for a formula and one for an equation, as presented by future chemistry teachers. According to the structure of glycerol presented in Table 3, students could incorrectly conclude that an oxygen atom is directly bonded to a hydrogen atom instead of a carbon atom. After a conversation with one future chemistry teacher, it was found that she does not realize the importance of proper writing of formulas, as she assumed that the students would understand them in the proper way. The second noticed imprecision refers to the writing of arrows in chemical equations. Although double-headed arrow implies the existence of a 'resonance hybrid', in this study, future chemistry teachers regularly used it to present an equilibrium condition. This is a well-known misinterpretation, explained by Bucat and Mocerino.[6]

Easy and smooth movement through the levels of representation of knowledge is very important for the development of chemical thinking and the development of proper mental models among students. To make these possible, students should be given the opportunity to meet and explore chemistry contents at all three levels, without neglecting certain levels or favouring others. In-service teachers, even university teachers do not pay sufficient attention to this, because as experts, they know the difference in use between macroscopic level as real and perceptually available and submicroscopic as real, but unavailable to direct sensory perception, or the difference in use between submicroscopic as real and symbolic as representational and assume that students will perceive them in the same way. However, for students, especially for those who have just started to study chemistry, it is difficult to perceive these differences. Therefore, it is important that teachers do not create additional confusion with inconsistent and inaccurate language within the triplet system. In line with that, it is essential that future chemistry teachers, in particular, become aware of the importance of accurate use of language, as being ones who will be in direct contact with novices, helping them to develop proper chemical concepts.

4. Conclusions

This study highlights areas of concern regarding submicro–macro and submicro–symbolic language. The main outcomes of this study are related to findings that future chemistry teachers tend to use imprecise language expressions in terms of particle types, prevalently using the term molecule regardless of the fact whether the compound is a covalent or ionic. It is also found that a vast majority of the covered sample avoided using particle terms, using macroscopic terms instead. Additionally, some concepts that belong to submicroscopic level were transferred to a bulk substance. Finally, concerning submicroscopic–symbolic relations, in one particular case, it was shown that future teachers do not pay the necessary attention to the terms that have different meanings in chemistry and in everyday life. Similarly, several issues in relation to submicroscopic–symbolic transitions were identified. It has been found that there were future chemistry teachers who reasoned at the symbolic level, and who did not have properly developed submicroscopic mental models. Furthermore, certain imprecisions regarding presentations of structural formulas have been noted as well. According to this, we may conclude that future chemistry teachers, which were involved in this study, did not possess adequate language accuracy within a triplet domain.

In light of this, we would like to emphasize the need to introduce students, future chemistry teachers, to the idea of the triplet model of content representation during their initial education. In accordance with that, students majoring in chemistry teaching should become aware of the importance of precise expression in this domain.

Regarding limitations of this study, it should be mentioned that studies with larger samples are needed before making any generalizations. Therefore, the findings of this study should be considered preliminary and additional research should be based on the cooperation with other university centres to be able to reach conclusions that are more general.

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6. References

1. J. K. Gilbert, D. F. Treagust, in: J. K. Gilbert, D. F. Treagust (Eds.): Multiple Representations in Chemical Education, Springer, Berlin, Germany, **2009**, pp. 1–8.

DOI:10.1007/978-1-4020-8872-8
2. A. H. Johnstone, *Sch. Sci. Rev.* **1982**, *64*, 377–379.
3. I. Devetak, M. Urbančič, K. Wissiak Grm, D. Krnel, S. Glažar, *Acta Chim. Slov*. **2004**, *51*, 799–814.
4. I. Devetak, J. Vogrinc, S. A. Glažar, *Res. Sci. Educ*. **2009**, *39*, 157–179. **DOI:**10.1007/s11165-007-9077-2
5. M. I. Stojanovska, B. T. Šoptrajanov, V. M. Petruševski, *Creat. Educ*. **2012**, *3*, 619–631. **DOI:**10.4236/ce.2012.35091
6. B. Bucat, M. Mocerino, in: J. K. Gilbert, D. F. Treagust (Eds.): Multiple Representations in Chemical Education, Springer, Berlin, Germany, **2009**, pp. 11–29. **DOI:**10.1007/978-1-4020-8872-8_2
7. B. Van Berkel, A. Pilot, A. M. W. Bulte, in: J. K. Gilbert, D. F. Treagust (Eds.): Multiple Representations in Chemical Education, Springer, Berlin, Germany, **2009**, pp. 31–54. **DOI:**10.1007/978-1-4020-8872-8_3
8. L. Mandić, J. Korolija, D. Danilović, Hemija za 7. razred osnovne škole, Zavod za udžbenike i nastavna sredstva, Beograd, **2009**, p. 61.
9. J. Adamov, N. Makivić, S. Olić, Hemija za 7. razred osnovne škole, Gerundijum, Beograd, **2012**, p. 72.
10. L. Mandić, J. Korolija, D. Danilović, Hemija za 8. razred osnovne škole, Zavod za udžbenike i nastavna sredstva, Beograd, **2010**, p. 129.
11. T. Nedeljković, D. Anđelković, Hemija 8, Novi Logos, Beograd, **2010**, p. 124.
12. M. Stojanovska, V. M. Petruševski, B. Šoptrajanov, *Nat. Math. Biotech. Sci*. **2014**, *35*, 37–46.
13. C. Horton, Student Alternative Conceptions in Chemistry, modeling.asu.edu/modeling/Chem-AltConceptions3-09.doc, (assessed June 24, 2014).
14. E. Adadan, Promoting High School Students' Conceptual Understandings of the Particulate Nature of Matter through Multiple Representations, Ph.D. Thesis, Ohio State University, **2006**.
15. G. D. Chittleborough, The Role of Teaching Models and Chemical Representations in Developing Students' Mental Models of Chemical Phenomena, Ph.D. Thesis, Curtin University, **2004**.
16. G. D. Chittleborough, D. F. Treagust, *Chem. Educ. Res. Pract*. **2007**, *8*, 274–292. **DOI:**10.1039/B6RP90035F
17. R. W. Kleinman, H. C. Griffin, N. K. Kerner, *J. Chem. Educ.* **1987**, *64*, 766–770. **DOI:**10.1021/ed064p766
18. V. Talanquer, *Int. J. Sci. Educ*. **2011**, *33*, 179–195. **DOI:**10.1080/09500690903386435
19. R. Vladušić, R. Bucat, M. Ožić, *Chem. Educ. Res. Pract*. **2016**, *17*, 474–488. **DOI:**10.1039/C6RP00037A
20. H. K. Boo, *J. Res. Sci. Teach.* **1998**, *35*, 3–12. **DOI:**10.1002/(SICI)1098-2736(199805)35:5<569::AID-TEA6>3.0.CO;2-N
21. K. S. Wissiak Grm, V. Ferk Savec, *Acta. Chim. Slov.* **2014**, *61*, 729–739.
22. K. S. Taber, *Educ. Chem.* **1994**, *31*, 100–103.
23. R. M. Kelly, L. L. Jones, *J. Sci. Educ. Technol.* **2007**, *16*, 413–429. **DOI:**10.1007/s10956-007-9065-3
24. L. T. Tien, M. A.Teichert, D. Rickey, *J. Chem. Educ.* **2007**, *84*, 175–181. **DOI:**10.1021/ed084p175
25. J. Othman, D. F. Treagust, A. L. Chandrasegaran, *Int. J. Sci. Educ.* **2008**, *30*, 1531–1550. **DOI:**10.1080/09500690701459897
26. H. D. Barke, *Bull. Chem. Technol. Bosnia Herzeg.* **2013**, *40*, 9–16.
27. B. M. Naah, M. J. Sanger, *Chem. Educ. Res. Pract*. **2012**, *13*, 186–194. **DOI:**10.1039/C2RP00015F
28. K. S. Taber, Chemical axioms, http://www.rsc.org/learn-chemistry/resource/res00001138/chemical-axioms?cmpid=CMP00002169, (assessed December 26, 2016).
29. R. Peterson, D. F. Treagust, *J. Chem. Educ*. **1989**, *66*, 459–460. **DOI:**10.1021/ed066p459
30. K. S. Taber, *Educ. Chem*. **1994**, *31*, 100–103.
31. K. C. D. Tan, D. F. Treagust, *Sch. Sci. Rev*. **1999**, *81*, 75–83.
32. R. K. Coll, D. F. Treagust, *J. Res. Sci. Teach*. **2003**, *40*, 464–486. **DOI:**10.1002/tea.10085
33. R. Vladušić, R. B. Bucat, M. Ožić, *Chem. Educ. Res. Pract.* **2016**, *17*, 685–699. **DOI:**10.1039/C6RP00040A
34. H. K. Boo, in: N. K. Goh, L. S. Chia, H. K. Boo, S. N. Tan, M. F. R. Tsoi (Eds.): Chemistry Teachers' Network, Singapore National Institute of Chemistry, Singapore, Singapore, **2000**, pp. 60–63.

Povzetek

Raziskava je osredotočena na pregled jezikovne natančnosti izražanja bodočih učiteljev kemije na področju makro–submikro–simbolnih domen. Ker je znanje na submikroskopskem nivoju ključnega pomena za razumevanje kemijskih konceptov in idej, je namen te raziskave preverjanje natančnosti jezikovnega izražanja bodočih učiteljev kemije na tem nivoju. V okviru tega cilja smo proučevali ali bodoči učitelji kemije med poučevanje pri jezikovnem izražanju razlikujejo med submikroskopskim in makroskopskim nivojem in tudi med submikroskopskim in simbolnim nivojem. Z uporabo kvalitativnih metod analize smo ugotovili, da večina bodočih učiteljev kemije, ki so sodelovali v raziskavi, nima zadosti natančnega načina jezikovnega izražanja glede proučevanih nivojev. Zaskrbljujoče je, ker pogosto bodoči učitelji kemije gledajo na natančnost jezikovnega izražanja na področju makro–submikro–simbolnih domen kot na nepotrebno komplikacijo in ne kot nujnost pri jasnem podajanju snovi.