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FOURTEEN-YEAR-OLD STUDENTS' MISCONCEPTIONS REGARDING THE SUB-MICRO AND SYMBOLIC LEVELS OF SPECIFIC CHEMICAL CONCEPTS

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Abstract. *Learning and presenting chemical concepts at the triple level of chemical concepts provides opportunities for the development of misconceptions. The research aimed to identify potential misconceptions of chemical concepts: the states of matter, a pure substance, a mixture, an element, a compound, a physical change, and a chemical reaction at the sub-micro level when solving problems incorporating sub-microrepresentations. A total of 188 14-year old students, attending six different primary schools, participated in the research. A chemistry achievement test comprising five problems at the macroscopic, sub-micro, and symbolic levels was used to obtain data about students' misconceptions of selected concepts. The results showed that the majority of students had formed inadequate mental models (misconceptions) for the chemical concept of the liquid state of water (66.5%). The lowest level of misconceptions is related with the gaseous state of matter, because almost all students (98.5%) solved the problem correctly. It can be concluded that the results of the research are significant for chemistry teachers because they can: select and apply adequate educational strategies to avoid the deepening or development of misconceptions and make the courses practically oriented by analysing students' misconceptions and develop teaching strategies to minimise these problems in the chemistry classroom.*
Keywords: *chemical concepts, primary school, misconceptions, sub-micro level, symbolic level.*

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Introduction

Chemical concepts are abstract for learning, since they can be represented at three different levels: i.e., at the macroscopic, sub-micro, and symbolic levels, presenting the so-called triangle of the triple nature of chemical concepts (Johnstone, 1982) (Figure 1). The macroscopic level comprises observable chemical concept presentations (e.g., experiments, movies, photos). At the sub-micro level, observations are explained by particle theories of matter. When the students understand the sub-micro level, the translation to symbolic level can be accomplished by using various chemical symbols, formulas, and equations (Devetak & Glažar, 2010; Slapničar, Svetičič, Torkar, Devetak, & Glažar, 2015; Wu, Krajcik, & Soloway, 2001).

Chittleborough (2014) stated that the understanding of the connection between all three levels of the representation of chemical concepts is not always adequate, since it can lead to the development of misconceptions. She believes, similar to Johnstone (1982), that it is necessary to include the macroscopic level in the teaching process. The other two levels of chemical concepts should be included in relation to the students' mental abilities and their pre-knowledge.

Chittleborough's models (2014) (see Figure 1b, c), founded on Johnstone's original triangle (1982) (see Figure 1a), show students' development of mental models as 'an expanding triangle' (the students' depth of knowledge at each corner of the triangle grows). Simultaneously, 'the iceberg model' serves as an analogy for students moving to higher levels of understanding as more of the symbolic and sub-micro level can be introduced when the horizontal line ('the sea level') moves towards the sub-micro and symbolic levels of understanding, as more of the iceberg is exposed above the sea level.

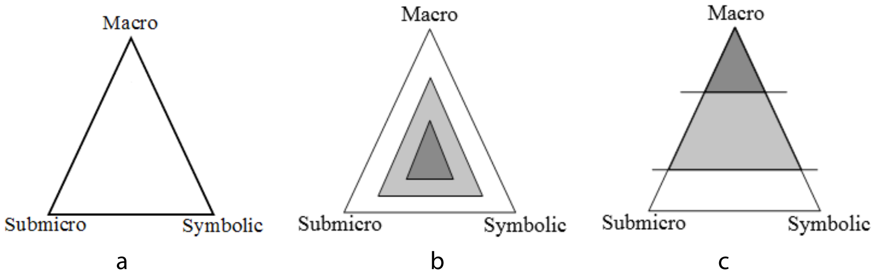

Figure 1. a - Johnstone's triangle of the triple nature of a chemical concept (Johnstone, 1982); b - Chittleborough's 'expanding triangle' and c - Chittleborough's 'rising iceberg' (adapted from Chittleborough, 2014).

In chemistry teaching, the integration of the triple nature of chemical concepts and the use of diverse educational materials and teaching approaches are essential for the adequate development of mental models of chemical concepts, which also affect problem-solving abilities (Slapničar et al., 2015, Slapničar, Devetak, Glažar, & Pavlin, 2017). Students successfully solve chemical problems when they can simultaneously and properly associate all three levels of chemical concepts (Taber, 2013). The success in solving chemical problems is also influenced by the students' pre-knowledge and experiences in a particular field (Avramiotis & Tsaparlis, 2013). Teachers ought to, for that matter, use appropriate visualisation tools to illustrate the correct connections between three levels of the representation of chemical concepts (Devetak & Glažar, 2010; Wu et al., 2001) and develop the ability to apply successful chemical problem-solving strategies (Turkoguz, 2012). Teachers can use animations of particles' interactions to present the sub-micro level (Kelly, Akaygun, Hansen, & Villalta-Cerdas, 2017). Such representations, also called sub-microrepresentations (SMRs), used as 2D or 3D static or dynamic aids, are analogous models of elements or compounds (Harrison & Treagust, 1998). Researchers (Bunce & Gabel, 2002; Devetak & Glažar, 2010; Eskilsson & Hellden, 2003; Kelly et al., 2017; Slapničar et al., 2017; Wu et al., 2001) have shown that chemical concepts are most often represented only at the symbolic level, which poses a greater possibility for students to develop misconceptions (Devetak & Glažar, 2010). However, students also have problems in understanding symbols derived from SMRs (de Berg, 2012; Falvo, Urban, & Suits, 2011; Johnstone, 1982; Stains & Talanquer, 2008).

Primary school students also have problems understanding the SMRs of matter and changing states of matter (Özmen, 2013). Ahtee and Varjola (1998) concluded that one quarter of 13- and 14-year-olds could not distinguish between the concepts of chemical and physical change. Schollum (1981) also stated that 70% of 14-year-olds could not recognise a physical change. Tóth and Kiss (2006) found that 13- to 17-year-olds had problems distinguishing between heterogeneous and homogeneous mixtures, pure substances and mixtures, as well as elements and compounds at the sub-micro level.

Furthermore, it has been well documented that Slovenian students have developed different misconceptions of chemical concepts at the sub-micro level, including the states of matter (Devetak, Drofenik Lorber et al., 2009; Devetak, Vogrinc et al., 2009). In a research by Devetak, Šket, Pozderec Intihar, and Glažar (2007), 13-year-old Slovenian students' understanding of the concepts element, compound, mixture, and state of matter presented at a sub-micro level was examined: 85.4% of students were successful in identifying a solid substance at the sub-micro level. Students were less successful in determining the SMRs of the compound (47.6%), the element (46.8%), the mixture of gases (41.5%) and the mixture of element and compound (39.0%). The results showed that 13-year-old students have the greatest difficulties in simultaneously determining two or three variables (e.g., a mixture and gaseous state of matter; a mixture, element and compound) (Devetak et al., 2007).

To avoid the formation of misconceptions, stimulating students' interest in learning chemistry is essential. Teachers can use different learning strategies to make those students who are not interested in chemistry but in other aspects of human activities aware that chemistry is a significant part of their lives. One such possibility is applying teaching in context (Parchmann, Blonder, & Broman, 2017), in which students can learn chemistry by making themselves aware that is a part of history and modern society (Milanovic & Trivic, 2017), industry (Marion et al., 2017), etc. Some studies have already been done (Parchmann et al., 2017; Milanovic & Trivic, 2017) showing that some contexts are more interesting than others for students, but further research is needed.

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Research Problem and Research Focus

According to the Slovenian curriculum in science, 11-year-old students (Grade 6) learn that matter consists of particles. They also learn about the distribution of particles in a specific state of matter. They know how to deduce the state of matter from the SMRs. Twelve-year-old students (Grade 7) learn about the concepts of physical change, chemical change, reactant, product, pure substance, mixture, element and compound, and their SMRs within the subject of science (Skvarč et al., 2011). Within the subject of lower secondary school chemistry, 13-year-old students (Grade 8) learn about the distribution and movement of particles in specific states of matter, the nature of particles in the element and the compound, the atom and molecule, and the symbols presenting elements and formulas presenting compounds. In Grade 9 (14-year-olds) learn about chemical reactions; balancing chemical equations, and translating SMRs to chemical equations (Bačnik et al., 2011).

From the presented theoretical background, a research problem arises, related to how 14-year-old students understand chemical concepts: 1) the states of matter, 2) a mixture, 3) a pure substance, 4) an element and a compound, 5) a physical change, and 6) a chemical reaction at the sub-micro and symbolic levels of representation. The research aimed to identify potential misconceptions of selected chemical concepts at the sub-micro level when solving problems incorporating SMRs.

From the research problem, one research question was formed: Which misconceptions about the state of matter, the pure substance, the mixture, the element, the compound, the physical change (at the sub-micro level) and the chemical reaction (at the sub-micro and symbolic levels) most frequently occur in Slovenian 14-year-old students?

Research Methodology

General Background

A quantitative (empirical) research approach with descriptive and non-experimental methods was used in this research. The data were collected by solving achievement test identifying the understanding of selected chemical concepts. The achievement test was applied in six Slovenian primary schools in April 2017.

Research Sample

Altogether 190 students were selected for the research. The non-random sample included 188 students (99.0 % - the percentage of the sample approached that participated) (90 girls and 98 boys), aged 14 years (M=14.0 years; SD=7.2 months), Grade 9, from six different primary schools located in Ljubljana and its surroundings. The students were selected from a mixed urban population. To ensure anonymity, each student was assigned a code consisting of a serial number. The students were selected based on their previously expressed interest in chemistry, their average achievements in science (their minimum grade was 3, whereby a grade of 5 represents excellent knowledge), and their communication skills. All participating students had learned chemical concepts for four years (primary school Grades 6 to 9; see the above description of courses in the subsection Research Problem and Research Focus).

Instrument and Procedures

A chemistry achievement test was used in this research. Three experts from the field of

chemical education developed the test, which consisted of eight problems at the macroscopic, sub-micro, and symbolic levels (the problems are presented in detail in the section Results of Research). Table 1 represents the structure of the achievement test, including the type of problem (task), problem number and Bloom's taxonomy level *(BTL),* variables of problems, concepts needed to solve the problems, difficulty *(p)* and discriminatory indexes *(D)*.

Table 1. Structure of the achievement test.

Type of problem	Problem number (BTL)	Variables	Concepts needed to solve the problem	p	D
Short answer	3 (part 3.1: first BTL; parts 3.2 and 3.3: second BTL)	Pure substances and mixtures	Pure substance, mixture, particle arrangement and characteristics	3.1 - .53 3.2 - .76 3.3 - .75	3rd problem: .66
	5.2 (third BTL)	Chemical reactions	Molecules, formulas of reactants and products, excess reactant, chemical equation	.09	5th problem: .58
	6 (second BTL)	Changing states of matter	Freezing, melting, vaporisation	6.1 - .48 6.2 - .43 6.3 - .89 6.4 - .76	6th problem .44
Multiple-choice with 1 correct answer	1 (first BTL)	States of water	Particle arrangement, particle characteristics, molecules, solid, liquid and gaseous state of water	.29	.56
	2a-d (first BTL)	Pure substances and mixtures	Mixture of gases, element in solid state of matter, mixture of elements, compound, particle arrangement and characteristics	2a - .59 2b - .98 2c - .35 2d - .51	2nd problem: .54
	8 (second BTL)	Changing states of matter	Sublimation, melting, boiling, heating, particle arrangement	.67	.39
Multiple-choice with more than 1 correct answer	2e (first BTL)	Gaseous state of matter	Gas, atoms, molecules, particle arrangement in a gas.	.99	2nd problem: .54
	4 (second BTL)	Physical change	Particle arrangement, physical and chemical change.	.57	.53
	5.1 (second BTL)	Chemical reactions	Molecules, reactants, products, excess reactant, elements, gas, formula of the product	.46	5th problem: .58
	7 (second BTL)	Pure substances and mixtures	Particle arrangement in a gas, mixture of element and compound/compounds/2 gases	.37	.59

The achievement test is reliable because its' internal consistency (Cronbach a = .65) was satisfactory. Discriminatory indexes for every problem (task) were higher than .40 (excepted for problem 8) and statistically significant - p <.0001. In almost all cases, the difficulty indexes were satisfactory (between .15 and .90), except for the problems 2b, 2e and 5.2. The content validity of the instrument was confirmed by three independent experts in chemistry, chemical education, and educational psychology, and the instrument checks the operational learning objectives listed in the curriculum of the subjects science and chemistry. The instrument was designed specifically for this research. The achievement test is economical, since it contains multiple-choice tasks and short answer tasks that can be quickly and easily evaluated.

Before the achievement test was applied, it was necessary to obtain consent from the students' parents, chemistry teachers and primary school boards. The research was conducted in six primary schools in April 2017. Students were given 30 minutes to complete the achievement test. All participants had the same test conditions (a quiet, relaxed environment).

Regarding the research problem presented in this article five problems from the achievement test have been chosen.

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Data Analysis

The relative frequencies of individual misconceptions of chemical concepts were determined for 14-year-old students. For the purposes of the conventional content analysis (coding categories derived directly from the text data) of misconceptions, students' responses to problems were converted into codes which were then used to form categories. As a criterion for identifying potential misconceptions of selected chemical concepts at the sub-micro and symbolic levels, an explanation was used that students misunderstand the chemical concept when they understand it in a way that does not correspond to its scientific explanation (Hasan, Bagayoko, & Kelley, 1999).

Student responses were encoded to facilitate data processing and statistically processed using SPSS.

Results of Research

With the first problem, it is possible to determine whether students can correctly attribute macroscopic representations of specific states of water to the corresponding SMRs. The particles of water are represented as single circles in the SMRs, and not as water molecules (see Figure 2).

To the photo of iceberg, add the letters (from A to C) of the schematic representations of water particles in three different states of water.

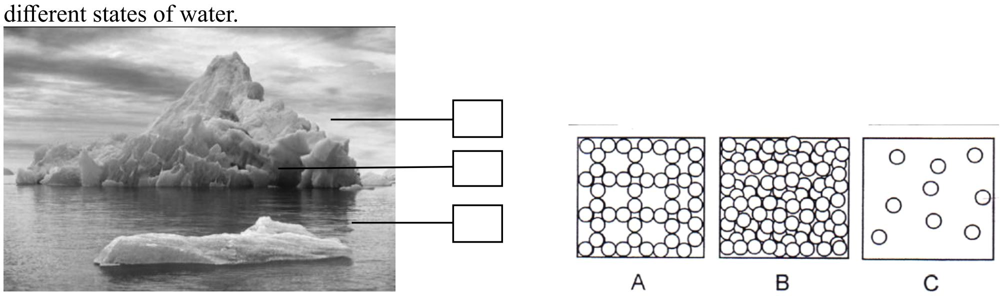


Figure 2. Problem 1 in the knowledge test – correct answer: water vapour in the air - SMR C, iceberg; solid state - SMR A, sea water; liquid state - SMR B.

Table 2 shows that the students (96.3%) were most successful in determining the SMR (C), characteristic of the gaseous state of water. In selecting the sub-micro representation for a liquid (B) or solid state (A), less than one third of students were successful.

Table 2. Relative frequencies of correct, wrong answers and no answers for Problem 1.

SMR for specific state of water	Correct answers (f %)	Wrong answers (f %)	No answers (f %)
C (gaseous state)	96.3	3.2	.5
A (solid state)	30.9	69.1	0
B (liquid state)	30.3	69.7	0

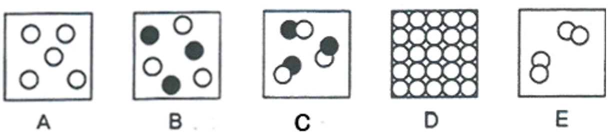
The most common misconceptions of the solid, liquid, and gaseous states of water at the sub-micro level are represented in Table 3. It is evident that most of the 14-year olds (68.6%) have developed a misconception about the solid state of water, because they did not distinguish between the arrangements of particles in a liquid and solid state of water. However, fewer students (66.5%) had difficulty in determining a representation typical of the liquid state of water. These students selected an SMR of the solid state of water. The incorrect selection of SMR for the gaseous state of water was very rare (3.2%).

Table 3. Relative frequencies of common misconceptions of the states of water.

Chemical concept	Misconception	f %
Solid state of water	Non-differentiation between SMRs of a liquid and solid state.	68.6
	Non-differentiation between SMRs of a gaseous and solid state.	.5
Liquid state of water	Non-differentiation between SMRs of a liquid and solid state.	66.5
	Non-differentiation between SMRs of a liquid and gaseous state.	3.2
Gaseous state of water	Non-differentiation between SMRs of a gaseous and solid state.	1.6
	Non-differentiation between SMRs of a gaseous and liquid state.	1.6

In Problem 2 (Figure 3), students had to choose among one of six SMRs that correspond to a mixture of gases, an element in a solid state of matter, a mixture of elements, a compound or gases.

The schemas from A to E show the distribution of particles in different substances.



For each substance described below, write the letter(s) from A to E, which corresponds to the distribution of particles in the schemas above.

a A mixture of gases is represented in schema ____
b An element in solid state of matter is represented in schema ____
c A mixture of elements is represented in schema _____
d A compound is represented in schema _____
e Gases are represented in schemas _____

Figure 3. Problem 2 in the knowledge test – correct answer: a – SMR B; b – SMR D; c – SMR B; d – SMR C; e – SMRs A, B, C and E.

Table 4 shows that slightly more than half of the 14-year-olds selected the appropriate SMR for the mixture of gases and the compound. A little over a third of the students chose the appropriate SMR for a mixture of elements. Almost all students were successful in determining the SMR for an element in a solid state of matter and SMRs for gases. When solving problem 2e, 71.3% of students selected only SMR (A) which shows the distribution of particles in a gas. SMRs A and B were selected by 2.1% of students, while A, B, C and E by 6.4% of students.

Table 4. Relative frequencies of the correct, wrong answers and no answers for Problem 2.

Problem	SMRs	Correct answers (f %)	Wrong answers (f %)	No answers (f %)
2a	Mixture of gases	58.5	41.0	.5
2b	Element in a solid state of matter	98.4	.5	1.1
2c	Mixture of elements	35.1	63.3	1.6
2d	Compound	51.1	47.8	1.1
2e	Gases	98.5	.5	1.1

Table 5 presents the most common misconceptions about mixture of gases, element in a solid state of matter, mixture of elements, compound and gases (at the sub-micro level) and their relative frequencies. The highest total percentage (59.0%) of misconceptions of individual chemical concepts is related to the mixture of elements. Among

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these, the most common misconception (35.1%) suggests that students do not distinguish between the concepts of mixtures of elements and compounds; however, another misconception indicates that 23.9% of students do not differentiate between the chemical concepts of element and the mixture of elements. Most students, therefore, have difficulty in defining two variables (mixture and element) and in distinguishing between pure substances (element and compound) and a mixture of elements at the sub-micro level. Misconceptions about compound are quite common, as they occur in more than a half of all students. The most common misconception is the non-differentiation between the molecules of the element and the molecules of the compound (38.8%). A total of 41.0% of students have developed misconceptions about the concept of a mixture of gases, which indicates difficulties in simultaneously determining two variables (the mixture and the gaseous state of matter).

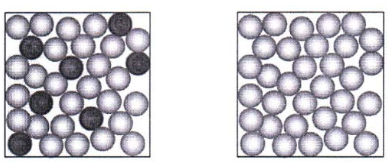
Table 5. Relative frequencies of the most common misconceptions of concepts tested in Problem 2 at the sub-micro level.

Chemical concept	Misconception	f %
Mixture of gases	Non-differentiation between the compound in the gaseous state and mixture of gases.	13.3
	Non-differentiation between element in the gaseous state and mixture of gases.	12.2
	Non-differentiation between element in the solid state and mixture of gases.	10.6
	Non-differentiation between a mixture of gases and gas.	4.9
Element in a solid state of matter	Non-differentiation between an element in the solid state and mixture of gases.	.5
Mixture of elements	Non-differentiation between the mixture of elements and the compound.	35.1
	Non-differentiation between an element and the mixture of elements.	23.9
Compound	Non-differentiation between the molecules of the element and the molecules of the compound.	38.8
	Non-differentiation between the mixture of elements and the compound.	7.4
	Non-differentiation between the atoms of the element and the molecules of the compound.	1.6
Gases	Non-differentiation between gas and solid substances.	.5

In the third problem (Figure 4), students had to determine the state of matter, represented on two SMRs (problem 3.1) and that they represent a pure substance (problem 3.2) and a mixture (problem 3.3). From the key, it was possible to discern what particles are represented in sub-micro representations.

Outlined are the distributions of particles of two substances.

First schema Second schema



Key:
lighter circles - the first substance
darker circles - the second substance

Compare the distribution of particles and answer the questions.

3.1 In which state of matter are the substances whose distributions of particles are represented in the first and second schema? ______
3.2 What can we conclude from the representation in the first schema? ______
3.3 What can we conclude from the representation in the second schema? ______

Figure 4. Problem 3 in the knowledge test – correct answers: 3.1–Substances in the first and second SMRs are in a liquid state; 3.2–The first SMR represents a mixture, mixture of substances or two elements; 3.3–The second SMR represents the pure substance or element.

Table 6 shows that three quarters of 14-year-olds in problem 3.2 and 3.3 identified a pure substance or mixture from SMRs of substances. More than half of the students found that the substances shown in the SMRs are in a liquid state.

Table 6. Relative frequencies of correct, wrong answers and no answers for Problem 3.

Problem	Correct answers (f %)	Wrong answers (f %)	No answers (f %)
3.1	52.7	43.6	3.7
3.2	75.5	16.0	8.5
3.3	75.0	12.8	12.2

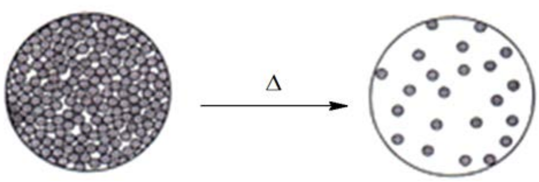
Table 7 presents the relative frequencies of common misconceptions of the concepts of the liquid state of matter, a mixture, and a pure substance. From the table, it is clear that the misconceptions of the concepts of pure substance and mixture are very rare; 6.3% of students do not distinguish between the mixture and the compound at the sub-micro level. Misconceptions about the liquid state of matter are quite common. Most often, the misunderstandings (38.8%) indicate that students do not distinguish between the SMRs of the liquid and solid states of matter.

Table 7. Relative frequencies of the most common misconceptions of the concepts of the liquid state of matter, mixture, and pure substance.

Chemical concept	Misconception	f %
Liquid state of matter	Non-differentiation between the liquid and solid state of matter.	38.8
	Non-differentiation between liquid and gaseous state of matter.	3.2
Mixture	Non-differentiation between a mixture and compound.	6.3
Pure substance	Non-differentiation between a mixture and pure substance.	2.7
	Non-differentiation between a compound and element.	.5
	Non-differentiation between an element and various elements.	.5

In Problem 4 (Figure 5), students had to recognise physical change and its properties from an *SMR*. In the case of a physical change (heating), there is no change in the substance but only in a redistribution of particles, which is a result of change in the state of matter.

The schema shows the distribution of particles in a substance before and after heating. Which statements are correct? To complete this task, ignore the number of particles in the schema.



a The distribution of particles has changed because a new substance has been formed.
b The substance has not changed, but the distribution of particles has changed.
c The substance has not changed because the distribution of the substance has not changed.
d A physical change of the substance has occurred.

Write the correct statements: ______________

Figure 5. Problem 4 in the knowledge test – correct answers: b and d.

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With Problem 4, 57.4% of the students answered the question correctly. They had chosen the answers related to the process of physical change and the change in the distribution of particles as presented with the SMR: 10.1% of the students chose only answer b (change in the distribution of particles), while 3.2% of the students only answer d (physical change). Therefore, 67.5% of students determined the characteristics of a physical change, while 60.6% of the students recognised the process of physical change from the SMR.

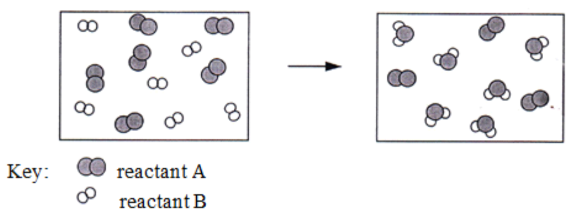
From Table 8, it is clear that most students have developed a misconception of the properties of physical change, related with the changing of matter. Students (6.4%) who wrote that physical changes do not influence the distribution of matter do not differentiate between the concepts of distribution of matter and distribution of particles, which means that they have difficulties in separating the macroscopic and sub-micro levels of the representation.

Table 8. Relative frequencies of the most common misconceptions of physical change.

Chemical concept	Misconception	f %
Physical change	Changing of matter.	21.2
	No change in the distribution of matter.	6.4

In Problem 5.1 (Figure 6), students had to determine from the SMR of a chemical reaction that the reactants are two elements and that the gas is a product of the chemical reaction. In Problem 5.2 (Figure 6), students wrote the chemical equation based on the SMR of a chemical reaction and key.

Schemas present the initial and final states of a chemical reaction at a particulate level. Compare the schemas and determine which statements are correct.



a During the chemical reaction, both reactants reacted completely.
b The product of a chemical reaction is a gas.
c Two elements reacted in a chemical reaction.
d The molecules with the formulae A_2B were formed.

5.1 Write the correct statements: ________________

5.2 Write the chemical equation of a chemical reaction: ____

Figure 6. Problem 5 in the knowledge test – correct answers: 5.1 b and c; 5.2 $A_2 + 2\ B_2 \rightarrow 2\ AB_2$.

For Problem 5.1, two students did not give an answer, while for Problem 5.2, 46 students (24.5%) did not write a chemical equation. For Problem 5.1, both correct answers (b and c) were given by 45.7% of students; 4.8% of students chose only answer b, while 9.6% of students only answer c. For Problem 5.2, 9.0% of the students wrote down the appropriate chemical equations; 43.0% of the students wrote the appropriate reactants of a chemical reaction, while 25.0% of students its appropriate products.

Table 9 represents the relative frequencies of the most common misconceptions of the chemical reaction at the sub-micro level (for Problem 5.1); 18.2% of students answered that in a chemical reaction both reactants reacted completely. Other misconceptions about chemical reaction were less frequent.

Table 9. Relative frequencies of the most common misconceptions about the chemical reaction at the sub-micro level.

Chemical concept	Misconception	f %
Chemical reaction	Both reactants reacted completely in the chemical reaction.	18.2
	Molecules with the formulae A2B were formed.	12.3
	Molecules with the formulae A2B were formed. Both reactants reacted completely in the chemical reaction.	.5

Table 10 presents the relative frequencies of the most common misconceptions of chemical reactions at the symbolic level (for Problem 5.2). It can be concluded that the most common misconception is that the chemical equations were completely miswritten (19.1%); 12.8% of students wrote the incorrect formulae for the products, and 12.2% of students also took into account the excess of reactant A_2 when writing down the chemical equation. Other misconceptions associated with the chemical equation are less frequent (7.0% of students or less).

Table 10. Relative frequencies of the most common misconceptions of the chemical reaction at the symbolic level.

Chemical concept	Misconception	f %
Chemical reaction	An incorrect chemical equation.	19.1
	Incorrect products in the chemical equation.	12.8
	An excess reactant (A2) in the chemical equation.	12.2
	One of the reactants in the chemical equation was written incorrectly, while the products were written correctly.	7.0
	Incorrect chemical equation, written according to the SMR by counting of molecules in the SMR.	5.9
	Unbalanced chemical equation with correct reactants and products.	4.8

The most of chemical concept misconceptions were presented in less than a fifth of 14-year-olds, which means that they were not frequent.

Discussion

The results have shown that 14-year-olds have developed misconceptions of concepts at the sub-micro level (the states of matter, a pure substance, a mixture, an element, a compound, a physical change) and the concept of chemical reaction at the sub-micro and symbolic levels. Almost all 14-year-olds have developed appropriate mental models of the gaseous state of water (96.3%) and the gaseous state of matter (98.5%), which is not consistent with the results of other research (Devetak et al., 2009), which stated that understanding the gaseous state of matter is difficult for students. Less than one third of 14-year-olds completely understand the concept of liquid and solid states of water at the sub-micro level. The most common misconception of the solid state of water (68.6%) is related to the non-differentiation between SMR of the liquid and solid states. Slightly fewer students (66.5%) selected the SMR of the solid state of water as the SMR representing the liquid state of water.

A little over a third of 14-year-olds identified a mixture of elements at the sub-micro level. More than half of the 14-year-olds correctly selected the SMR of the compound and mixture of gases (compound - 51.5%, mixture of gases - 58.5%), which is more than shown in previous research (Devetak et al., 2007), which included 13-year-olds (compound - 47.6%, mixture of gases - 41.5%). It can be concluded that students also have problems in determining two variables (mixture and two elements, mixture and two gases), as was also shown by Devetak et al. (2007) (mixture and two gases). When identifying an element in a solid state of matter, most of the students had no problem (98.4% of students answered correctly). Students often expressed a misconception of a compound, related to the non-differentiation between the SMR of molecules of an element and the molecules of a compound (38.8%). This is in accordance with other research (Tóth & Kiss, 2006), which showed

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that students, aged between 13 and 17, had developed misconceptions about the concepts of element and compound at the sub-micro level.

A total of 35.1% of 14-year-olds did not distinguish between the mixture of elements and the compound at the sub-micro level (when selecting the SMR of the mixture of elements), meaning that they have difficulty understanding the concepts of a pure substance (element, compound) and mixture (mixture of elements). A lower percentage of 14-year-olds (23.9%) did not differentiate between the element and the mixture of elements at the sub-micro level (when selecting an SMR of a mixture of elements). Three quarters of 14-year-olds recognised a pure substance and mixture from an SMR, which is similar to the results obtained by Tóth and Kiss (2006). A total of 60.6% of students recognised the process of physical change, which is somewhat less (by 9.4%) than in the research (Schollum, 1981). Our research showed that 67.5% of 14-year-olds were successful in determining that particles are rearranged during physical change, but fewer students (60.6%) recognised that the SMR represents physical change. The most common misconception of physical change (21.2%) is related to the fact that students think that physical change is actually a chemical reaction. 18.2% of the students thought that both reactants completely reacted during a chemical reaction, which is the most common misconception of the concept of this specific example of chemical reaction at the sub-micro level. The most common misconception of the concept of a chemical reaction at the symbolic level (19.1%) is related to the completely incorrectly written chemical equations. The results also showed that 14-year-olds have problems in identifying the products of a chemical reaction from the SMR (12.8% - incorrect formulas of the product in the chemical equation; 12.2% - the unreacted reactant as the product of a chemical reaction). These results are consistent with the results of other researches (de Berg, 2012; Falvo et al., 2011), which showed that students have difficulties using the symbolic level (writing chemical equations) based on SMRs.

Therefore, most of the obtained results are consistent with the fact that the sub-micro level is more difficult for students to understand, which is related to the invisibility of the particles in matter (Herga, Glažar, & Dinevski, 2015; Mumba, Chabalengula, & Banda, 2014). Particles of matter would be better presented with 3D dynamic SMRs instead of 2D static SMRs (representation of particles with circles). This kind of representation promotes the development of an adequate mental model of the chemical concept (Olakanmi, 2015). It can be concluded that using information technology (ICT) is crucial in creating a better understanding of chemical concepts (Machková, & Bílek, 2013; Sarabando, Cravino, & Soares, 2016).

Conclusions and Implications

The research aimed to identify potential misconceptions of 14-year old students of basic chemical concepts: the states of matter, a pure substance, a mixture, an element, a compound, a physical change, and a chemical reaction at the sub-micro level of chemical concepts when solving problems incorporating SMRs. The results of the research have shown that students have developed misconceptions about all researched chemical concepts at the sub-micro level. On the basis of the obtained results of the research, teachers can teach selected chemical concepts to 14-year-olds in a way that prevents the development or deepening of misunderstandings. All this leads to the higher quality of students' further education.

If the sub-micro level is excluded, the majority of students (91.0%) have developed misconceptions about the concept of a chemical reaction at the symbolic level, which is the most abstract level of understanding. Based on these results, it can be concluded that 14-year-olds are not yet able to understand the concept of a chemical reaction at a symbolic level or the concept is not adequately taught in school chemistry.

For the development of appropriate mental models of chemical concepts, it would be necessary for chemistry teachers to use different learning approaches. In this context, the use of visualisation tools (especially dynamic SMRs) is crucial, as is an appropriate explanation of the key features of representations. It is also necessary that teachers stimulate students' interest by applying context and inquiry-based chemical education. Such approaches would undoubtedly contribute to students' higher achievements in chemistry. The poor understanding of certain concepts can also be influenced by the fact that most Slovenian textbooks for chemistry are designed to contain most representations at the symbolic level, which is the most complex for understanding. It would be sensible that all teaching materials contain many more representations of chemical concepts at all three levels simultaneously, as this would improve the understanding of chemical concepts.

Limitations of this research are: 1) the chemistry achievement test should include more problems with different chemical concepts at all three levels of representation to identify more specific misconceptions, 2) the chemistry achievement test could be multi-tier so that misconceptions could be identified more objectively, and 3) the research sample was small.

Future research in the field of misconceptions should be regarding the triple nature of chemical concepts and involve: 1) the analysis of the problem-solving strategies in relation to the development of abstract thinking, which is essential in identifying the level of understanding of abstract chemical concepts (sub-micro and symbolic levels of representation); 2) a comparison between urban and rural schools and between female and male students; 3) a triangulation of data collection; 4) using 3 or 4-tier test questions would shed more light on specific misconceptions and diminish the possibilities of false positive or false negative answers; 5) using eye-tracking methodology for identifying students' information processing during problems solving.

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