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The macroscopic, submicroscopic and symbolic level in explanations of a chemical reaction provided by thirteen-year olds

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Abstract: The aim of this research was to investigate whether pupils aged 13, at the end of their first year of studying chemistry, are capable of perceiving the macroscopic and the submicroscopic level of the previously learned contents on chemical reactions, and whether they relate them to the chemical equations (the symbolic representation). Another aim was to establish how much demonstration experiments contribute to a better linking of the mentioned levels. The research featured 69 pupils of the seventh grade from three primary schools. The pre-test was conducted, following which experiments were demonstrated, and the post-testing was carried out in the end. After the intervention, a total of 12 pupils were interviewed about which aspects of chemical reactions they thought of based on the chemical equations. A statistically significant difference in two out of five requirements of the post-test, compared to the pre-test, indicate that the demonstration experiments may contribute to a better linking of three levels of representing chemical reactions. However, when one compares the pupils' answers in the test and in the interview, it can be observed that the correct answers in the test are not always based on understanding the concepts in connection with the chemical reaction.

Keywords: chemical reaction; chemical equation; demonstration experiment; primary school.

INTRODUCTION

Identifying pupils' problems when it comes to understanding the basic concepts in chemistry is important for planning the teaching process that will serve to avoid those problems, or to overcome them if they have already appeared. They may be hidden because pupils' success at solving problem tasks is not always the result of deep conceptual understanding but may be due to a reproduction of a familiar algorithm used to solve a particular problem.[1] For this

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reason, it is necessary to examine what kind of reasoning pupils use while solving various tasks from the key areas of chemistry.[2]

Researches point to the fact that pupils think about a chemical reaction as a process of adding or mixing molecules, without any clear idea of the mechanism of the given chemical reaction.[3,4] Also, pupils' answers indicate that, when they recognise that it is a matter of a chemical reaction, at the same time they do not view it at the level of atoms and molecules and do not recognise that the law of conservation of mass applies, while some recognise only a physical change instead of a chemical reaction.[3,4] For pupils of different age, the request to simultaneously review chemical reactions at three levels of representation is rather challenging: the macroscopic level, where on the basis of observation one may describe substances and changes in their properties, for example, reactions that occur between substances in solution in which one of the products is insoluble, the submicroscopic/particle level, that is, the level of atoms, molecules and ions, and the symbolic level, where the structure of the given substance and interactions between atoms, molecules and ions are represented by means of chemical symbols, formulas and chemical equations.[5] The connections between these different levels of presenting chemical reactions are that which is not obvious to pupils and what distinguishes their reasoning from that of chemists.[6,7] Striving to interpret chemical reactions at the micro level, pupils resort to memorising chemical equations – the symbolic level of presenting chemical reactions.[8] Even though they, within the framework of many laboratory exercises and observing experiments, write equations of chemical reactions and mathematically determine coefficients (which should provide information to them about quantitative relations in chemical reactions at the submicroscopic level), they do not necessarily perceive the interconnectedness of these curricular contents and activities.[9] Demonstrations of chemical reactions are a part of usual curricular activities, the aim being for observations at the macroscopic level to facilitate pupils' understanding of chemical reactions.[10] Researches have shown that the most difficult thing for pupils is to think about the structure of substances (the submicroscopic level) and to interpret at that level the properties and changes of substances that they perceive at the macroscopic level.[9,11–15]

A chemical equation, as one of the key models in chemistry, serves to explain, quantitatively and qualitatively describe a chemical reaction, linking the macroscopic and the submicroscopic level of a chemical reaction.[16] Researches suggest that the understanding of secondary school pupils and college students is predominantly in the realm of the symbolic,[1,17–19] which may be due to the abstract nature of the particulate structure of a substance[20], and consequently the inadequate mental models of students.[21] The ability to present a chemical reaction at the symbolic level does not guarantee the ability to understand a reaction at the level of particles. In one research, of the 65 % of secondary school pupils who correctly determined the coefficients in a chemical reaction, more than half of them could not present that chemical reaction at the particle level.[22] Also, pupils were not sure how the symbolic level was connected with the perceived properties and changes of substances at the macroscopic level or chemical bonds in substances presented by means of chemical formulas.[9,23] When determining the coefficients in chemical equations, they often follow certain algorithmic procedures without any deeper consideration of the meaning of coefficients.

On the other hand, a research conducted on a sample of secondary school pupils aged 15–16 showed that pupils' ability to use multiple levels of representation can be improved.[24]

According to the curriculum for primary school in Serbia, the pupils start studying chemistry as a separate teaching subject in the seventh grade of primary school (aged 13). The chemistry curriculum for the seventh grade encompasses five topics: Chemistry and its Importance, Basic Chemical Concepts, Structure of Substance, Homogeneous Mixtures – Solutions, and Chemical Reactions and Calculations. The themes Structure of Substance and Chemical Reactions and Calculations comprise three levels of representing chemical concepts. The question that arises is what mental representations for chemical reactions are formed by thirteen-year-old pupils and what connections between various levels of representation (the macroscopic, submicroscopic and symbolic level) they can establish and understand.

Demonstration experiments are considered to be an important support for the purpose of forming concepts in chemistry teaching. For successful chemistry teaching, it is important to review their role and contribution to the linking of the macroscopic, submicroscopic and symbolic levels at which chemical reactions are reviewed.

EXPERIMENTAL

The aim of the research

The aim of this research was to investigate whether pupils aged 13, at the end of their first year of studying chemistry, are capable of perceiving the macroscopic and the submicroscopic level of the previously learned contents on chemical reactions, and whether they relate them to the chemical equations (the symbolic representation). In addition to this, we wished to establish to what extent the observation of demonstration experiments stimulates pupils to review chemical reactions at the level of the structure of reactants and products (atoms, ions and molecules), and how they link observations at the macroscopic level with various ways of representing substances and chemical changes by means of models and chemical symbols, formulas and chemical equations. From the aims thus defined, there arose the following research questions:

1. Which connections between various levels of representing chemical reactions (the macroscopic, submicroscopic and symbolic level) do thirteen-year-old pupils establish and understand?

2. What is the contribution of demonstration experiments to understanding chemical reactions by thirteen-year-olds?

3. What information on a chemical reaction on the basis of a chemical equation do thirteen-year-olds accept?

The sample

The research involved the participation of pupils from three seventh grade classes from three different schools on the territory of Belgrade (one class from each school). The sample encompassed a total of 69 pupils (42 boys and 27 girls). All the pupils did a test. Of the overall number of pupils in the sample, 12 were selected by random choice (four pupils from each class) and were interviewed.

Before commencing the research, the management of every school and chemistry teachers were acquainted with the aim of the research and the manner of its realisation. The school managements and chemistry teachers gave their agreement for conducting the research, and a contract of cooperation was signed by the Dean of the Faculty of Chemistry and the principals of the schools involved. The pupils' participation in the research was voluntary, and their score in the test did not influence their chemistry marks.

Design and procedure

One classroom period (lasting 45 min) was conducted with each class comprising the sample. The classroom period, which is designed as review of the previously learned contents on chemical reactions, consisted of three parts (see Table I). In the first and the third segment of the work, the pupils were given the same test to solve. During the second segment of the work, the teacher demonstrated three experiments related to three tasks comprising the test. After observing the demonstration, the pupils talked with the teachers about the properties and changes of the substances used in the experiments observed. Also, the pupils wrote the chemical equations of the reactions. The following experiments were demonstrated:

1. obtaining hydrogen and hydrogen combustion;
2. magnesium combustion;
3. obtaining carbon dioxide and its reaction with a barium hydroxide solution.

These demonstrations involve the macroscopic visible indicators that chemical reactions occur, which are explained in all currently used chemistry textbooks for the seventh grade.

After the classroom period, four pupils from each class were interviewed.

TABLE I. Research design

Classroom period segment	Duration, min	Activity
I	12	Pre-testing
II	21	Experiment demonstration
III	12	Post-testing
After the intervention	4×7 to 8	Interview

Instruments

For the purpose of conducting the research, we used a test (Supplementary material to this paper, Addendum 1) and the interview protocol (Supplementary material, Addendum 2). The same test was used for the pre-testing and for the post-testing. The test comprises three tasks, containing a total of five requirements. The tasks were associated with three levels of representing chemical contents, previously elaborated under the curriculum themes: Structure of Substance and Chemical Reactions and Calculations. This means that different levels of representations were known to the students before this research. The three tasks in the test relate to the three experiments that were demonstrated to the pupils after the first test and subsequently discussed with them.

The purpose of the pre-test was to establish the level of the pupils' knowledge about chemical reactions at the end of the seventh grade, after they had dealt with the entire chemistry curriculum envisaged for that year of primary school. The post-test, using the very same tasks, was conducted in order to examine whether the pupils have made any progress when it came to connect the macroscopic, submicroscopic and symbolic levels of presenting chemical reactions, after observing the demonstration experiments and discussing them, compared to the pre-testing. These demonstrations are directly related to the requirements in the test. In this way, it was possible to monitor the students' reasoning associated with the demonstrations and the influence of them on linking macroscopic, submicroscopic and symbolic levels of representing chemical reactions. Everything was done during one classroom period, in order to establish the effects that can be expected from this period of chemistry instruction.

Using the interviews, data were gathered on what aspects of chemical reactions the pupils thought about and what information they accepted from the equations of chemical reactions.

The validity of the test in terms of the aim of the research was checked by the chemistry teachers working in the schools encircled by the sample. The teachers' estimate was that the test corresponded to the chemistry curriculum for the seventh grade of primary school.

RESULTS AND DISCUSSION

The parameters of the results distribution in the pre-test and the post-test are presented in Table II.

TABLE II. The parameters of the results distribution in the pre-test and the post-test (the maximum number of points was 5)

Test	*N*	Min	Max	Mean	*SD*	*p*	Skewness	Kurtosis
Pre-test	69	0	4	1.93	1.18	38.6	–0.022	–1.086
Post-test	69	0	5	2.87	1.27	57.4	–0.235	–0.482

The value of the t-test indicates that the difference between the arithmetical means in the two tests is statistically significant (Table III).

TABLE III. The paired samples t-test (pair 1, pre-post)

Paired samples test; Paired differences			95 % confidence Interval of the difference		*t*	*df*	Sig. (2-tailed)
Mean	*SD*	*SE* mean	Lower	Upper			
–0.94	1.862	0.224	–1.39	–0.50	–4.202	68	0.000

Table IV presents the percentage of the pupils' correct answers to each task in the pre-test and the post-test, as well as the values of the *t*-test, which was used to evaluate the statistical significance of the difference in the percentage of correct answers in the two tests.

TABLE IV. The percentage of correct answers to the tasks in the pre-test and the post-test

Task	Number of correct answers in the pre-test	Contribution, % of correct answers in the pre-test	Number of correct answers in the post-test	Contribution, % of correct answers in the post-test	*t*-test
1A	44	63.8	55	79.7	2.00[a]
1B	26	37.7	25	36.2	–0.18
2a	17	24.6	20	29.0	0.56
2b	37	53.6	41	59.4	0.66
3	9	13.0	39	56.5	5.20[b]

[a]Confidence interval 95 %; [b]confidence interval 99 %

A statistically significant difference in the pupils' results in the two tests related to item 1A (Table IV) points to the fact that, after observing a demonstration of the reaction of hydrogen combustion and a discussion about the observed change in terms of the particles involved, the pupils are more capable of relating the chemical change described in the task to the corresponding chemical equation. The pupils who did not provide the correct answer in the pre-test but did so in the post-test did not know that the reactants were in the form of two-atom molecules, or did not pay attention to the coefficients in the equation of that chemical reaction (in other words, they neglected the law of conservation of mass). However, the number of answers to item 1B in the pre-test and the post-test points to the fact that, even after being presented a demonstration and discussing the experiment, a little less than two-thirds of the pupils still failed to link the change with the corresponding reactant molecules and the product in this reaction. They still do not show that they are capable of reviewing a chemical reaction at the submicroscopic level, and the number of correct answers to this task was even somewhat lower in the post-test. When one compares the pupils' achievements in the post-test pertaining to items 1A and 1B, it is evident that a little more than half of those pupils who provided a correct answer to item 1A failed to do so in the case of item 1B. The lower number of correct answers is partly the consequence of the pupils' failure to understand the meaning of the index in chemical formulas and the coefficients in chemical equations, and also of their failure to join the description of an experiment and the symbolic notation with the submicroscopic level. The respondents' better score in the tasks that are related to the symbolic level of presenting chemical reactions, than in those related to the interpretation of chemical reactions at the submicroscopic level has also been established in other researches featuring pupils from an older age group.[22,25]

In item 2a, a chemical change was described – the combustion of magnesium. To provide help, the atomic numbers of magnesium and oxygen were given. The pupils were expected to write a chemical equation on the basis of the information provided, and in doing so, to apply the knowledge from the lessons on the ionic bond, valence and the synthesis reaction they have dealt with during the school year. The requirement to write a chemical equation was fulfilled by a smaller number of pupils related to item 1A, which required of them to recognise the correct chemical equation among those given. An error frequently made by the pupils involved the wrong index in the formula of magnesium oxide (those are the answers MgO_2, Mg_2O). The replies of 10 pupils in the pre-test showed that they thought the atomic numbers of magnesium and oxygen were actually their indexes (they did not pay attention to the way in which the numbers were written next to the symbol of the corresponding element), and some of them thought that the product of the coefficient and the index of the reactant had to be equal to the atomic number. Those pupils did not repeat this mistake in the post-test.

However, while dealing with this reaction at the submicroscopic level, in item 2b, on the basis of the model of the structure of atoms and ions, the pupils were more successful than in item 1B. The number of correct answers related to this task in the post-test increased in relation to the pre-test, but the difference in the percentage of the correct answers in the two tests is not statistically significant.

The percentage of the correct answers related to the item 3 was statistically significantly higher in the post-test in relation to the pre-test. Solving the task was based on a picture showing the apparatus for the unfolding of two chemical reactions (the macroscopic level of representation). Observing the demonstration of the experiment and the resulting discussion contributed to a statistically significant increase in the number of the correct answers to the item three in the post-test in relation to the pre-test. This result has important implications for the practice sessions, where there are not enough demonstration experiments and the students are observing the given experiment in textbooks. The test results indicate that the observation of experiments has a considerably greater influence on the pupils' knowledge than illustrations of experiments in textbooks.

Interview analysis

The actual level of knowledge supporting the increase in test scores was to be shown by the interviews conducted after the second test with 12 randomly selected pupils (four pupils from each class). Table V details their answers in both tests and their chemistry marks, expressed on a scale of 1 (the lowest and failing grade) to 5 (the best grade). The pupils were marked by letters from A to L.

Table VI presents the pupils' answers as to what a chemical reaction equation represents and what information it provides.

The pupils' answers show that the majority of them notice the qualitative meanings of chemical reaction equations, and that fewer of them also notice the quantitative meanings. From the answers of some of the pupils, one can see their efforts to link the symbolic and the submicroscopic levels, which refers to the structure of reactants and the products of chemical reactions.

TABLE V. The answers of the pupils interviewed in the pre-test and the post-test, and their chemistry marks; the correct answers are marked by capital letters in bold print. The incorrect answers were marked by small letters, not in bold print. In task 2a, the letter n marks an incorrect answer, the letter **T** a correct answer, whereas the sign / indicates that the pupil in question skipped this item

Pupil	Answers in the pre-test					No. of correct answers	Answers in the post-test					No. of correct answers	Chemistry mark
	1A	1B	2a	2b	3		1A	1B	2a	2b	3		
A	**B**	c	n	b	b	1	**B**	d	**T**	A	**A**	3	4
B	**B**	d	n	**C**	c	2	**B**	d	**T**	**C**	**A**	4	4
C	**B**	d	n	b	b	1	**B**	d	**T**	B	**A**	3	4
D	a	a	n	b	b	0	**B**	a	**T**	B	**A**	3	3
E	**B**	d	**T**	b	d	2	**B**	d	n	**C**	**A**	3	4
F	a	d	**T**	**C**	b	2	**B**	d	**T**	**C**	b	3	3
G	d	**B**	/	b	c	1	**B**	**B**	n	B	b	2	2
H	a	**B**	/	**C**	c	2	**B**	**B**	**T**	**C**	d	4	5
I	**B**	c	**T**	**C**	b	3	**B**	c	**T**	**C**	**A**	4	5
J	**B**	a	**T**	**C**	b	3	**B**	**B**	**T**	**C**	**A**	5	5
K	**B**	c	**T**	**C**	**A**	4	**B**	c	**T**	**C**	**A**	4	5
L	**B**	c	**T**	**C**	**A**	4	**B**	c	**T**	**C**	**A**	4	5

TABLE VI. The pupils' answers to the questions: What does a chemical reaction equation represent? What information does a chemical reaction equation provide?; the numbers in brackets indicate the number of points scored in the pre-test and the post-test, and the pupil's mark in chemistry

Pupil	Answer
A (1; 3; 4)	Provides information on what reacts and what is obtained.
B (2; 4; 4)	I can see molecules.
C (1; 3; 4)	How many atoms, that is, reactants, were used to achieve equality.
D (0; 3; 3)	How a substance is created. For example, how water is created from hydrogen and an oxide.
E (2; 3; 4)	I can see the reactants and the products. Substances that react and create some new substance.
F (2; 3; 3)	I see valences, how many moles there are, the relations in which reactants react.
G (1; 2; 2)	I can see the elements.
H (2; 4; 5)	I can see the change that occurs when two elements react with each other and produce a new compound.
I (3; 4; 5)	One can see the reactants and the products.
J (3; 5; 5)	I can see how two elements form a bond. I can see how many atoms a compound contains, and of what atoms that compound consists.
K (4; 4; 5)	I can see how two elements react and a compound is obtained, how many atoms an element contains, I can see the formulas.
L (4; 4; 5)	How to obtain some compound.

From the pupils' answers to the question what the coefficients in a chemical reaction equation represent (Table VII), it is evident that they do not understand the coefficients as the stoichiometric ratios of reactants and products (with the exception of pupils D and F). To most of the pupils interviewed, the coefficients are numbers used to balance the chemical equations. Also, pupils tend to confuse the meanings of the terms coefficient and index, as evidenced by the answers of pupils G, H, I and K.

TABLE VII. The pupils' answers to the question: What do the coefficients in a chemical reaction equation represent?; the numbers in brackets indicate the number of points scored in the pre-test and the post-test, and the pupil's mark in chemistry

Pupil	Answer
A (1; 3; 4)	How much there is of that substance... How to determine what the equation should be like at the end, how everything is to be correctly determined.
B (2; 4; 4)	Those are the numbers written in front so that everything should be equalised.
C (1; 3; 4)	We use them to determine the equation.
D (0; 3; 3)	How much we need of which substance in order to produce water, for example, how much hydrogen we need and how much oxygen.
E (2; 3; 4)	The coefficient represents multiplied molecules.
F (2; 3; 3)	They represent the number of moles.
G (1; 2; 2)	That is the number showing how many elements there are.
H (2; 4; 5)	That is the number in front of a compound or element. Through those numbers I can see how many atoms an element has.
I (3; 4; 5)	They represent the number of atoms in a molecule.
J (3; 5; 5)	They represent how many elements there are in a compound and how many compounds are produced when two reactants react.
K (4; 4; 5)	They indicate how many atoms there are. If it says H_2, then there are two hydrogen atoms.
L (4; 4; 5)	We see how many molecules there are. For example, if it says $3H_2O$, it means there are three molecules of water.

To the third question, why it is important to determine the coefficients in a chemical equation, most pupils answered it is in order to balance the equation (A, B, C, F, H). The answers of pupils D, I, J and K implicitly indicate that there is a connection between coefficients and stoichiometric ratios, but they were not well formulated terminologically. Pupil G has no idea why coefficients are important, whereas pupil L confuses the meanings of the terms coefficient and index. The only complete answer was provided by pupil E: "For example, regarding the reaction of the production of water, from the equation where the coefficients have been determined we see that it takes twice as much hydrogen to produce water, which you can't see from an equation where the coefficients have not been determined. That is why we determine them, so that we know the quantity of a substance that is needed."

From the pupils' answers to the question what is the difference between a coefficient and an index (Table VIII), it is evident that pupils A, D and F confuse the meanings of these terms. Pupil H states that the difference lies in the place of writing the coefficient and the index in relation to the formula of the substance, whereas pupil K mentions the place of writing them and provides an explanation from which one cannot see the difference in the meaning of coefficient and index.

TABLE VIII. The pupils' answers to the question: What is the difference between a coefficient and an index? the numbers in brackets indicate the number of points scored in the pre-test and the post-test, and the pupil's mark in chemistry

Pupil	Answer
A (1; 3; 4)	The index... that is, the coefficient, shows how many atoms there are in that substance, and as for the index... I don't know what index is.
B (2; 4; 4)	When we have an index, that can be because of the valence, and then... We can know the index because of the valence, and then you add the coefficient to equalise that.
C (1; 3; 4)	The coefficient applies for that whole part (points at the formula), and the index only applies to one atom.
D (0; 3; 3)	The coefficient is natural, and we add the index for the formula to be right.
E (2; 3; 4)	The index is how many atoms we have in a molecule. The coefficient marks how much of that substance we have. Specifically, in the example of the equation for a chemical reaction producing water, the coefficient 2 in front of hydrogen means that we have two molecules.
F (2; 3; 3)	(Points to the equation for a chemical reaction producing water) The coefficient is this little number 2 that stands to the right of oxygen and hydrogen, and the indexes are the big 2's in front of hydrogen and water.
G (1; 2; 2)	The coefficient is the number of how much hydrogen there is and stands on the left (points to the equation for a chemical reaction producing water). And I've forgotten what the index is.
H (2; 4; 5)	The coefficient is placed in front, and the index is the small number afterwards.
I (3; 4; 5)	The index determines the number of atoms in a molecule, for example O_2, and the coefficient also determines the number of atoms, only it is placed in front and applies to all the atoms in that molecule, and the index is just for one atom.
J (3; 5; 5)	The coefficient is always written in front, and it can mark how many particles, that is molecules, atoms, there are, and the index is determined by those particles, how many there are.
K (4; 4; 5)	The coefficient stands in front and the index after a symbol. The coefficient tells me how many atoms there are, and the index tells me the same, I suppose.
L (4; 4; 5)	The index stands after the atom and determines... I mean, it also determines, but some molecules have two atoms, and that is why the index is written, and the coefficient is written in front and applies to the whole compound, how many atoms it has, and the index is just for that atom that is in front of it.

The majority of the pupils did not mention the quantitative relation between reactants and products when they answered about the meaning of chemical equation (Table VI). However, they considered the ratios of substances that mutually react when they were explicitly asked about that (Table IX). The answers presented in Table IX point to the fact that determining the coefficients is an activity that pupils conduct by following the algorithm.

Three out of twelve pupils (I, G and D) answered that from a chemical reaction equation they cannot see the regrouping of the atoms of the reactants (Table X).

TABLE IX. The pupils' answers to the question: Can you see, from the equation of a chemical reaction, the ratios of substances that mutually react?; the numbers in brackets indicate the number of points scored in the pre-test and the post-test, and the pupil's mark in chemistry

Pupil	Answer
A (1; 3; 4)	I can see how much there is of what.
B (2; 4; 4)	I don't know.
C (1; 3; 4)	It can't be determined precisely.
D (0; 3; 3)	I can see, for example, how much hydrogen and oxygen there is in an equation so that water can be produced.
E (2; 3; 4)	Until the coefficients are determined, we can see how much of what there is in a compound, and we see what the reactants are and how many of them there are, which create that one compound.
F (2; 3; 3)	Presumably I can, on the basis of a compound. For example, how many atoms an element in the compound has.
G (1; 2; 2)	You can see how much there is of what, for example, how many atoms there are.
H (2; 4; 5)	In an equation we can see how many atoms of one reactant there are, and how many of the other.
I (3; 4; 5)	You can see the ratio of the substances reacting. I see that four atoms of hydrogen react with two atoms of oxygen.
J (3; 5; 5)	I can, by means of coefficients and indexes.
K (4; 4; 5)	The quantitative aspect can be seen by means of the coefficients, but the ratio cannot be seen from the equation of a chemical reaction.
L (4; 4; 5)	We can, on the basis of indexes and coefficients.

TABLE X. The pupils' answers to the question: Can you see the regrouping of the atoms from a chemical reaction equation?; the numbers in brackets indicate the number of points scored in the pre-test and the post-test, and the pupil's mark in chemistry

Pupil	Answer
A (1; 3; 4)	I can see it from the reactants and the product.
B (2; 4; 4)	I see that hydrogen was separated from oxygen, and then the coefficient was added in order to equalise it.
C (1; 3; 4)	If we see that there is H_2 and also O_2, then we have to regroup so that it is equalised.
D (0; 3; 3)	I really don't know.
E (2; 3; 4)	I see molecules before and after the reaction.
F (2; 3; 3)	(Points at the equation of the chemical reaction producing $BaCO_3$ from $Ba(OH)_2$ and CO_2) I see that barium was in a compound with oxygen and hydrogen, and after the reaction with carbon and oxygen.
G (1; 2; 2)	I don't know how to see that regrouping.
H (2; 4; 5)	I can see how they change places.
I (3; 4; 5)	I can't see that.
J (3; 5; 5)	I can see with what an element formed a compound before the reaction, and with what after the reaction.
K (4; 4; 5)	I see what is produced.
L (4; 4; 5)	I see from the formula.

On the basis of a chemical reaction equation, the pupils' answers to the question if they imagined particles colliding shows that they only perceive the regrouping of atoms through the initial and the final state of the reaction in question, without reviewing the movement of particles and their collisions (Table XI). Pupils C and I were reminded of the process of dissolving, probably under the influence of the animation of this process presented during one of the previous lessons. According to their answers, they did not distinguish the physical and chemical changes. Moreover, their explanations of the process of dissolving were incorrect.

TABLE XI. The pupils' answers to the question: On the basis of a chemical reaction equation, do you imagine particles colliding?; the numbers in brackets indicate the number of points scored in the pre-test and the post-test, and the pupil's mark in chemistry

Pupil	Answer
A (1; 3; 4)	It did interest me, but no one explained that to us and I have no idea about it.
B (2; 4; 4)	I have no idea about it.
C (1; 3; 4)	I tried to imagine. For example, if we place bluestone in water and it dissolves and colours the water blue, that is, it switches from the solid aggregate state to liquid.
D (0; 3; 3)	I have never imagined that.
E (2; 3; 4)	Not really. I only know that it is necessary for them to collide for a reaction to happen, that's what it says in the book.
F (2; 3; 3)	I don't know.
G (1; 2; 2)	I have never imagined it.
H (2; 4; 5)	I've no idea.
I (3; 4; 5)	Well, I can describe it, our teacher showed us various photos, what that looks like. When a substance dissolves in water, then the molecules of water disintegrate, and as for the substance dissolved in water, all its particles dissolve in water, for the molecules of water took those particles, those bits, and that was how it dissolved.
J (3; 5; 5)	I haven't imagined it.
K (4; 4; 5)	I have never imagined it.
L (4; 4; 5)	Well, for example, we have one oxygen and two hydrogens colliding in order to get water.

Of the 12 pupils interviewed, item 1A was solved correctly by 8 of them in the pre-test, while all the pupils gave the correct answer in the post-test. Progress was made by pupils D, F, G and H. However, the answers given by pupils D and F during the interview indicate that they still confuse the meaning of coefficients and indexes (Table VIII). Pupils G and H think that in chemical equations "coefficients mark the number of atoms", which is probably the result of an application of algorithm in the process of determining coefficients.

In dealing with item 1B, only pupil J made progress. The answers that this pupil gave during the interview indicate that he understands the terms coefficient and index, but he has a problem when it comes to expressing this in words. Pupil G, who has a mark 2 in chemistry and whose answers in the interview indicate that his knowledge of chemistry is poor, solved task 1B correctly on both occasions.

Task 2a, wherein the pupils were required to write the equation of the chemical reaction of magnesium combustion, was correctly solved by six of the pupils interviewed in the pre–test, and in the post-test 10 of them provided the correct solution. The incorrect answers in the pre-test were as follows:

pupils A and B: $6Mg_2 + O_6 \rightarrow 6Mg_2O$;

pupil D: $Mg + O_2 \rightarrow MgO_2$;

pupil C: $2Mg + 2O_2 \rightarrow 2MgO_2$.

In the answers given during the interview, these pupils stated that "the equation must be balanced", but they made mistakes when it came to applying the knowledge of valence during the process of compiling a formula of the compound formed by those elements. Pupil C does not understand that coefficients in a chemical equation represent the stoichiometric ratios. In the post-test, these four pupils wrote the correct chemical equations of magnesium combustion. Two of the pupils interviewed did not provide the answer to item 2a in the pre-test. One of those two pupils wrote the correct chemical equation in the post-test, and the other correctly presented the reactants and the product of the chemical reaction in terms of symbols and formulas, but did not determine the coefficients.

Dealing with item 2b, of the 12 pupils interviewed, seven provided the correct answer in the pre-test, and eight in the post-est. Progress was made by pupil E.

Of the 12 pupils interviewed, two of them (K and L) gave the correct answer to the third task in the pre-test, and nine of them did so in the post-test. Progress was made by pupils A, B, C, D, E, I and J.

CONCLUSION

Researches that have been conducted so far have mostly related to the problems faced by secondary-school pupils and older students when it comes to linking the macroscopic, submicroscopic and symbolic levels of presenting chemical reactions. According to the chemistry curriculum for primary schools in Serbia, pupils are first taught the concept of a chemical reaction at the age of thirteen and, which is important for the purpose of the further planning of the teaching process, to identify their first notions of a chemical reaction, especially in the view of the fact that they are expected to interpret that concept at various levels.

On the other hand, it was important to ascertain to what extent the observing experiments helped pupils at that age to understand the concept of a chemical reaction, and also whether, through the application of this method, they improved their ability to interpret a chemical reaction at various levels. The results obtained by administering the same test before and after watching demonstration experiments showed a statistically significant difference in the pupils' achievements, when they were asked to identify the correctly written chemical equation and to identify a chemical reaction/chemical reactions at the macroscopic level. However, watching demonstration experiments neither did influence the pupils' ability to write chemical reaction equations, nor did it help them interpret chemical reactions at the submicroscopic level. This is in line with the comments of some researchers.[9]

The results of this research correspond to the results achieved by older pupils, when it came to linking the various levels of presenting chemical reactions. Comparing the pupils' answers given in the test with those given in the course of the interview indicates that they can be successful at writing indexes in chemical formulas and at determining coefficients in chemical equations, while remaining unsure of the actual meaning of the terms coefficient and index. This indicates that pupils can solve tasks successfully by using algorithms, and that their success is not always connected with in-depth conceptual understanding.

The ideas of thirteen-year-old pupils of how particles behave during a chemical reaction are unclear. Most often, they review a chemical reaction only through the equation, from the point of view of the initial and the final state, without any idea of how the reaction actually proceeds.

The answer given by the thirteen-year olds during the interview reveal that after the demonstrations and a discussion, and after they had successfully solved the tasks in the post-test, the problems related to the meaning of indexes in chemical formulas and coefficients in chemical equations still remained. In other words, the fact that they had better results in the post-test does not mean that they have a better understanding of chemical reactions and that they are capable of linking the macroscopic, submicroscopic and symbolic levels of presenting chemical reactions. That should be taken into consideration in the teaching practice in the future, especially the fact that the pupils' success at recognising the chemical equations and writing them does not necessarily mean that they perceive a chemical reaction at the level of the structure of the given substance, at the level of the particles that make it up and at the level of the chemical bonds. In other words, focusing on explaining chemical reactions on the basis of chemical equations does not necessarily mean that the pupils will have an idea of what goes on during the reaction at the submicroscopic level.

Most researches have dealt with the problems faced by students, especially freshmen, but if we manage to eliminate the problems that beginners encounter in the study of chemistry and lead them to form a functional system of chemical concepts, we could expect them to be more successful in their education later on.

The limitations of the research

One limitation of this research is the insufficient sample, which prevents generalisations. Also, when pupils were randomly selected to be interviewed, it turned out that in that segment of the sample three-quarters of the respondents had a mark of 5 (the best grade) or 4 in chemistry. That is why the problems pertaining to the reasoning of those pupils whose marks in chemistry are lower were not sufficiently manifested. Also, in the further research the students whose score decreases in the post-test should be chosen for the interview and the reasons for that should be examined.

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И З В О Д

МАКРОСКОПСКИ, СУБМИКРОСКОПСКИ И СИМБОЛИЧКИ НИВО У ОБЈАШЊЕЊИМА ХЕМИЈСКЕ РЕАКЦИЈЕ ТРИНАЕСТОГОДИШЊАКА

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Циљ овог истраживања је да се испита да ли ученици узраста 13 година на крају седмог разреда сагледавају макроскопски и субмикроскопски ниво представљања претходно наученог садржаја о хемијским реакцијама, и да ли та два нивоа повезују с хемијским једначинама (симболичким представљањем хемијских реакција). Други циљ је био испитивање доприноса демонстрационих огледа у бољем повезивању наведених нивоа. У истраживању је учествовало 69 ученика седмог разреда из три основне школе. Изведено је почетно тестирање, затим су демонстрирани огледи и на крају је изведено завршно тестирање. Након сваког часа, интервјуисано је 12 ученика о томе о којим аспектима хемијских реакција размишљају на основу једначина хемијских реакција. Статистички значајна разлика на два од пет захтева завршног тестирања, у односу на почетно тестирање, указује да демонстрациони огледи могу допринети бољем повезивању макроскопског, субмикроскопског и симболичког нивоа представљања хемијских реакција. Међутим, када се упореде ученички одговори на тесту и интервјуу уочава се да иза тачних одговора на тесту не стоји увек разумевање појмова у вези с хемијском реакцијом.

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