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ADDRESING STUDENTS' MISCONCEPTIONS CONCERNING CHEMICAL REACTIONS AND SYMBOLIC REPRESENTATIONS

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Abstract. The purpose of the study was to investigate the ideas of students about some basic chemical concepts, such as dissolving, burning, structure of ionic substances, as well as reactions involving gases, external condition and limiting reagents. Also of interest was the way students understand and use symbolic representations in writing equations or representing entities of which substances are composed. Two types of data-collection techniques were used: (1) quantitative (administration of a six-item instrument in a pre-test–post-test design) and (2) qualitative (implementation of individual interviews with students). The target population for this investigation consisted of high-school students ($N = 149$) from several schools in Macedonia. The study was aimed to evaluate the effectiveness of an intervention program including deepened explanations, models, experiments, discussions and web animations on the cognitive achievement of students. The overall scores of the students were significantly higher in the post-test, thus pointing out the efficiency of the intervention program and the benefits gained during instruction. One-way ANOVA analysis showed that the four sub-samples (representing the students from four levels of study) were statistically different from one another both in the pre-test and in the post-test. In addition, the post hoc testing revealed that not all mean differences among pairs of sub-samples were statistically significant. Further on, *t*-tests were used to inspect the effect of gender and interviews on students' achievement. More than 15 misconceptions were registered both by test and interview analysis. Several of them, which could be characterized as deep-rooted misconceptions, remained (almost) unchanged after implementing the intervention program.

Keywords: high-school chemistry education, misconceptions, chemistry teaching, chemical reactions, symbolic representations, interviews.

Introduction

Chemistry is a conceptual subject based on a number of abstract concepts. It is likely, therefore, that students may have difficulties in understanding and explaining such concepts. Among these, some basic concepts are present, in one way or another, at all levels of chemical teaching – from the first exposition of the students to chemistry in the elementary schools and upwards. Naturally, various concepts about chemical reactions and their symbolic representations have a central place in the chemistry curricula, thus making this topic applicable for investigation across all levels of students' populations. For our study, the detection of the presence of erroneous concepts (misconceptions) in the mind of students is of primary importance.

Many misconceptions have been documented[1,2)] and studies investigating misconceptions and difficulties in learning and understanding chemical concepts have been reported (Chiu, 2007; Cliff, 2009; Kariper, 2011; Morgil & Yörük, 2006; Mulford & Robinson, 2002; Nyachwaya et al., 2011; Onwu & Randal, 2006; Taber, 2011; Wenning, 2008). Among others, erroneous notions have been recorded (Çalýk et al., 2005; Demircioğlu, 2009) in explaining concepts such as burning, physical and chemical changes, dissolving and solutions. According to Sirhan (2007) the development of misconceptions is not only students' fault and may originate from previous knowledge of students (Roschelle, 1995), the usage of everyday or specific scientific terminology, from textbooks (Nelson, 2003; Taber, 2001), teachers or the teaching itself. The latter is often a reason for the appearance of erroneous notions sometimes referred to as *school-made misconceptions* (Barke et al., 2009).

Teaching chemical reactions (and many other topics as well) implies usage of three levels of thinking (Johnstone, 2000): the macroscopic, the submicroscopic and the representational and these should be utilized in that order. Many misconceptions are due to the confusion between the macroscopic and submicroscopic properties of matter held by the students (Ben-Zvi et al., 1986; Bucat, 2004; Chandrasegaran et al., 2007; Meijer, 2011; Treagust et al., 2011). Employing the three levels simultaneously leads to an "overload of their working memory space" (Sirhan, 2007). Neglecting the submicroscopic one, on the other hand, may be a basis for the appearance of various misconceptions and this is especially important when dealing with chemical reactions. Namely, in order to understand changes during chemical reactions and give proper explanations, one must be able to apply the submicroscopic level of thinking. On the other hand, it is necessary to utilize the symbolic "shortcuts" (chemical equations) for representing the reactions. However, too often, chemical reactions are learned solely through symbolic representations, thus stimulating only the rote learning (Dhindsa & Treagust, 2009; Salame et al., 2011).

Our present study deals with misconceptions held by high-school students in Macedonia and associated with some aspects of chemical reactions, their symbolic representations and the type of particles involved. The results from the concept test, as a rough estimate of students' understanding and identifying potential misconceptions, as well as opinions from in-depth interviewing are summarized in this paper.

Objectives

The main objective of this study was to identify potentially present misconceptions among high-school students of different age. In order to accomplish this, the general knowledge of high-school students regarding chemical reactions and their ability to apply learned concepts are investigated. At the same time, the study was intended to check the capability of students to transfer their knowledge through the three levels of thinking as well as the ability to distinguish between physical and chemical properties.

Furthermore, the study was aimed to evaluate the effectiveness of an intervention program on cognitive achievement of students while interviews were utilized to locate further misconceptions held by students of different levels of study.

The investigation was guided by the following research questions: (1) does the intervention program improve students' achievement in the post-test; (2) are there any trends in understanding of the tested concepts by students across various levels of study; (3) are the mean differences among four sub-samples statistically significant; (4) is there a difference between the male and female in the testing; (5) is there a difference between the interviewed and non-interviewed students in the testing; (6) are there any (and if so, what are they) misconceptions present in students' thinking regarding the topics on chemical reactions.

Methodology of research

Design

The study consisted of two parts: (1) quantitative (administration of a six-item instrument in a pre-test–post-test design) and (2) qualitative (implementation of individual interviews with students).

At a certain point of this research an intervention program was introduced, including deepened explanations, models, experiments, discussions and web animations.[3-7] We believed that the animations and molecular models would be beneficial to students in visualizing the building particles and could be helpful in explaining the phase changes and the chemical reactions that involve a limiting reactant. The intention was to correct erroneous ideas which students had and to promote an active learning environment, thus increasing students' interest, motivation and participation in the teaching process.

The experiments prepared as an integral part of the conceptual change instruction were: (a) burning of a magnesium ribbon; (b) burning of ethanol; (c) dissolving sodium chloride and anhydrous copper(II) sulfate in water, evaporating the solvent and comparing the chemical nature of the substance(s) before and after the change; (d) reactions between $HCl(g)$ and $NH_3(g)$; (e) precipitation reactions performed on watch glasses (laboratory experiments carried out by the students, one example being shown in Fig. 1): $Pb(NO_3)_2 + KI$, $HgCl_2 + KI$, $FeCl_3 + K_4[Fe(CN)_6]$, $FeCl_3 + KSCN$, $AgNO_3 + KI$ и $BaCl_2 + H_2SO_4$.

The developmental stages of the investigation are briefly stated as follows: administration of the pre-test; analysis of the pre-test data using the software package PASW 18.0; recording misconceptions and identifying the students holding them; conducting the interviews; preparing transcripts and analyzing each interview; implementation the instruction program; administration of the post-test; analyzing the post-test data using the software package PASW 18.0.

Sample of research

The data for this study were collected in four high schools in Republic of Macedonia in the 2010/11 school year. The data were collected in a period from April to June 2011.

The instrument was administered to a total of 149 high-school students. The students were further grouped according to the level of study into a four sub-samples. It is stated in the literature (Hoque et al., 2011) that the minimum number of subjects for experimental research is 30 so that the number of participants in this study is quite sufficient for further analysis.

At the beginning of the interviewing process, a total number of 62 participants were purposively selected from the sample students. They were categorized into three sub-groups: high achievers, middle achievers and low achievers. Details concerning participants involved in the study are shown in Table 1.

Fig. 1. Precipitation reaction example (reaction between KI and $Pb(NO_3)_2$)

Table 1. Information on participants involved in the study

Level of study	City	Number of participants		Number of interviewed students		
		Female	Male	High-achievers	Middle-achievers	Low-achievers
I	Kumanovo	30	20	8	8	9
II	Negotino	21	16	6	3	5

III	Skopje	16	17	5	4	2
IV	Skopje	16	13	9	2	1
Total		83	66	28	17	17

Data collection

Data were collected through two kinds of instruments: concept tests of chemistry and individual interviews. The usage of both quantitative and qualitative data collection techniques leads to an improvement of the validity of results by means of triangulation (Hussein, 2009; Jick, 1979).

Concept test

A "pre–post" design was used to examine concepts that students had and to reveal if any misconceptions were present. A concept test was distributed both before and after the intervention (interviews and instruction). The test items were developed by the authors and, following the suggestions by Herrmann-Abell & DeBoer (2011), the potential misconceptions were used as distractors. Ideas for using some misconceptions as distractors were found in other literature sources as well[2,8,9] (Kind, 2004; Yezierski & Birk, 2006).

The test contained examples of equations of chemical reactions, equations being present in practically every chemistry textbook, starting from the beginning of learning chemistry as a subject. The test questions were rather general, so they were appropriate for students at any level of study.

Interviews

Our purpose was not only to review the students' tests, but also to get an in-depth insight into their thinking using interviews as an appropriate technique, interviews being successfully used as data collection techniques in educational research (Canpolat, 2006; Singh, 2008; Sözbilir et al., 2010; Taber & Watts, 2000). To accomplish this, 62 semi-structured in-depth individual interviews were conducted. The questions asked by the researcher were open-ended, thus offering possibility to develop detailed discussion and promote understanding. Especially important for our study were the ideas and explanations given by students and the examples or reasons offered for their statements.

According to their earlier performance in chemistry, the high-school students were categorized into three sub-groups: high achievers, middle achievers and low achievers. Students, who agreed to participate, were interviewed in an empty classroom or laboratory. They were told that the test results and interview discussions will be used for research purposes only and were guaranteed that the research will not affect their grade. The interviews were audio-taped, the duration of each being 15–20 minutes. They were carried out according to the design proposed by Kvale (1996). An interview guide was prepared beforehand, but more questions emerged during discussion depending on students' answers. After the interviewing process has finished, transcripts were made for each interview, making the data handling easier.

Data analysis

In the concept test, each fully correct response was scored 1 point (for the first three questions) or 2 points (for the other questions). In this way, the maximum score was 13 points. Predictive Analytics Software (PASW) 18.0 was used for analyzing the data. Means, standard deviations (SD) and significance testing were used to summarize data. The results of the pre- and post-tests were compared using pared-samples *t*-test. Independent-samples *t*-test was used to test the differences between males and females and the effect of the interviews in the pre-test and in the post-test. One-way ANOVA was performed on the pre- and post-test scores separately, to examine if mean differences were significant among students representing the four levels of study.

The percentage of correct answers to the test items as well as that of wrong ones was considered. The latter could indicate presence of students' misconceptions on the tested concepts (Dhindsa & Treagust, 2009). Namely, a statement represented as a distractor can be considered a misconception if it is chosen by more than 20 % of the students. On the other hand, correct answers given by approximately 75 % of the participants (for items with four distractors) can serve as an indicator of the satisfactory conceptual understanding. The misconceptions that were identified for over 20 % of the students are reported in the next section.

The interview transcripts were used to locate gaps in knowledge and segments that can be considered as misconceptions. All interviews were conducted in Macedonian, so the excerpts quoted in this paper were translated into English.

Results and discussion

The data showed improvement in achievements of students in the post-test. It can be noticed (Fig. 2) that students from all levels of study accomplished better results in the post-test, although these are not as high as we have expected. Results of both (pre- and post-) tests are rather low; the average scores are 5.39 for the pre-tests and 6.05 for the post-tests. In our opinion these results are more due to lack of knowledge than to deep-rooted misconceptions. Still, some erroneous concepts were identified in the thinking of students of different age.

In the framework of the first research question, the null hypothesis was stated as: "There is no significant difference in the pre- and post-test results". A paired-samples *t*-test was conducted and tested at the 0.05 level to evaluate if there was any significant difference between scores from the pre- and post-tests. The results of the pre- and post-test for all sub-samples as well as for the total sample were compared (Table 2). The overall scores of the students were significantly higher in the post-test, thus pointing out to the efficiency of the intervention program and the benefits gained during instruction (interviews, experiments, discussions and explanations). Having this in mind, the null hypothesis was rejected. The findings, also, indicate that students from higher levels of study preformed much better and experienced significantly higher results in the post-test when compared to the pre-test.

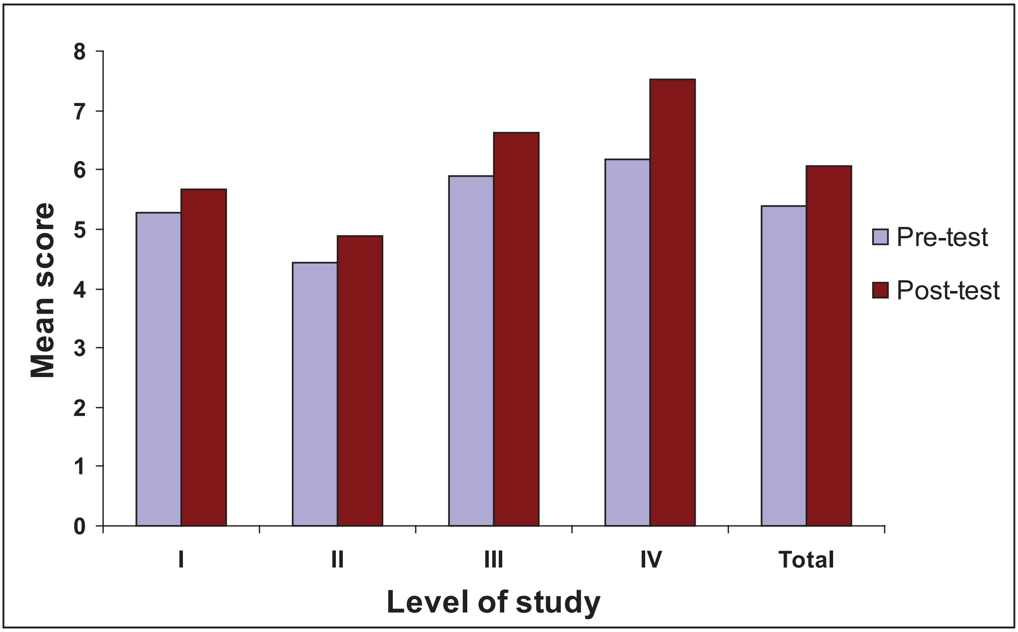

Fig. 2. Pre-test and post-test means comparison

Table 2. Paired-samples *t*-test analysis results comparing pre-test and post-test scores

Level of study	**Pre-test**			**Post-test**		
	N	**Mean**	**SD**	**Mean**	**SD**	***t*-values**
I	50	5.29	1.64	5.67	2.01	1.42
II	37	4.45	1.57	4.89	1.70	1.33
III	33	5.89	1.95	6.64	2.14	2.08 *
IV	29	6.17	1.80	7.52	1.77	3.30 *
Total	149	5.39	1.83	6.05	2.12	3.99 *

$^{*}p < 0.01$

The trend in understanding of the tested concepts by students across the various levels of study (research question 2) is noticeable, *t*-values increasing from the first-year students to the fourth-year ones. It should be pointed out that there is some irregularity regarding this trend. Namely, the results from the second-year students deviate from the others by being lower. The reasons for this behaviour are not clear. One possible explanation may be that these low results in achievement of the second year students are perhaps related to the poorer educational conditions in smaller towns in Macedonia. The second-year students' sample came from Negotino, which is the smallest among the three towns covered by this research.

Further on, one-way ANOVA procedure was used to test the hypothesis that the means of the four sub-samples are equal (according to the pre- and the post-test). The analysis showed that the four sub-groups were statistically different from one another in the pre-test ($F = 6.65$, $p = 0.000$) and in the post-test ($F = 11.77$, $p = 0.000$), thus the null hypothesis can be rejected.

Next, it was useful to identify where these differences exist by post hoc testing. The third research question was stated as: "Are the mean differences among four sub-samples statistically significant?" In order to answer this question, a null hypothesis was formulated: $\bar{x}_1 = \bar{x}_2 = \bar{x}_3 = \bar{x}_4$. The post hoc analysis found that the null hypothesis can not be rejected only for the comparison of sub-samples 1 and 3, and 3 and 4 in the pre-test and for sub-samples 1 and 2, and 3 and 4 in the post-test (Table 3).

Table 3. Comparison of the mean differences of the sub-samples

Level of study	Level of study	*p* (pre-test)	*p* (post-test)
I	II	0.026	0.064
	III	0.122	0.027
	IV	0.030	0.000
II	I	0.026	0.064
	III	0.001	0.000
	IV	0.000	0.000
III	I	0.122	0.027
	II	0.001	0.000
	IV	0.528	0.074
IV	I	0.030	0.000
	II	0.000	0.000
	III	0.528	0.074

As stated before, the fourth research question refers to the estimation of the gender difference in the pre- and post-testing. Considering the mean scores it can be concluded that males did better in the pre-test, but the mean score for females was higher in the post-test. An independent-samples *t*-test was conducted to determine if there was any significant difference between females and males in the pre- and post-test separately. The analysis did not yield any significant difference at the 0.05 level between the mean scores of the responses by the female and those of the male participants, both in pre- and post-testing (Table 4). Note the negative values for the *t*-statistics for pre-test analysis. The negative sign is due to the fact that the mean score for females is lower than that of males in the pre-test.

An enhancement in the test scores could be observed both by females and males. In order to reveal the differences in the mean scores according to gender, a paired-samples *t*-test was performed. The female participants showed a higher degree of enhancement measured by the concept test. The improvement was found to be statistically significant for females ($t = 3.58$, $df = 82$, $p = 0.001$), but not significant for males ($t = 1.90$, $df = 65$, $p = 0.062$).

Table 4. Independent-samples *t*-test analysis results
for the gender effect on the pre- and post-test

	Gender	***N***	**Mean**	**SD**	***t***	***p***
Pre-test	Female	83	5.31	1.85	– 0.59	0.557
	Male	66	5.49	1.80		
Post-test	Female	83	6.16	2.21	0.68	0.495
	Male	66	5.92	2.01		

The fifth research question investigated the effect of interviews to the students' performance on the tests. The differences in the mean scores in the pre- and in the post-test were compared using separate independent-samples *t*-tests. Paired-samples *t*-test was conducted to check for significant differences in improvement between interviewed and non-interviewed students. Independent-samples *t*-test analysis (Table 5) revealed no significant difference between the two groups of students (interviewed and non-interviewed) in the pre-test, which means that their previous knowledge is comparable.

Table 5. Independent-samples *t*-test analysis results
for the interview effect on the pre- and post-test

	Interview	***N***	**Mean**	**SD**	***t***	***p***
Pre-test	Yes	83	5.48	1.80	0.55	0.582
	No	66	5.32	1.85		
Post-test	Yes	83	6.48	2.29	2.13	0.035
	No	66	5.74	1.95		

The interviews were performed after the initial testing (pre-test) and, regarding the post-test results, the analysis showed that interviewed students exhibited significantly higher results than the non-interviewed ones.

Paired-samples *t*-test was also run to inspect the enhancement of the interviewed and non-interviewed students. The analysis showed that not only the interviewed but also the non-interviewed students experienced higher results in the post-test compared to the pre-test ($t = 1.98$, $df = 86$, $p = 0.051$). However, the improvement of the interviewed students was found to be statistically significant ($t = 3.85$, $df = 61$, $p = 0.000$) emphasizing the benefits of conduction interviews.

With respect to the sixth research question for the misconceptions present in the students' thinking, the written responses of students were used to estimate the gain in conceptual understanding and to locate the possibly present misconceptions. For each test item some distractors were favoured, thus several misconceptions were identified. The percentages of each chosen option for certain test item were calculated and presented in the tables that follow. For better clarity, the correct options in the tables were bolded. Interview discussions were also used either to confirm the misconceptions found by the test analysis or to indicate the existence of new ones.

In addition, some comments from the interviews are given and the excerpts presented in the paper could enable readers to examine the trustworthiness of the research procedure. After every excerpt a brief description is given that includes the level of education (given by Roman numerals) and the sub-group to which the student belongs. The abbreviations "S" and "R" stand for "student" and "researcher", respectively. In some cases, excerpts from pre- or post-tests are given and they are appropriately marked.

Table 6. Percentage of chosen options to the first test item

Year of study		a		**b**		c		d		Other[1]	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	I	0.0	2.0	36.0	66.0	4.0	16.0	60.0	12.0	0.0	4.0
	II	13.5	2.7	18.9	70.3	29.7	18.9	35.1	8.1	2.7	0.0
	III	15.2	3.0	60.6	48.5	3.0	9.1	21.2	33.3	0.0	6.1
	IV	10.0	3.3	66.7	93.3	10.0	3.3	3.3	0.0	10.0	0.0
	Total	8.7	2.7	43.3	68.7	10.7	12.7	34.0	13.3	3.3	2.7

[1] In this column, the values represent the total percentage of students who either did not answer the question or chose more than one option.

Item 1: In the first test item we asked: "What happens with NaCl entities in aqueous solution?" The possible answers were: a) molecules are formed; b) ions are formed; c) both molecules and ions are formed and d) sodium and chlorine are formed.

Item 2: The second test item referred to a similar concept. Namely, we were interested in the opinions of students about the nature of pairs such as Na^+ and Cl^-. The students could chose whether these are: a) molecules; b) ions; c) both molecules and ions and d) elementary substances.

Table 7. Percentage of chosen options to the second test item

		a		**b**		c		d		Other	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Year of study	I	0.0	0.0	98.0	98.0	2.0	2.0	0.0	0.0	0.0	0.0
	II	0.0	0.0	94.6	89.2	2.7	2.7	2.7	5.4	0.0	2.7
	III	6.1	3.0	87.9	97.0	3.0	0.0	3.0	0.0	0.0	0.0
	IV	0.0	0.0	90.0	96.7	3.3	3.3	0.0	0.0	6.7	0.0
	Total	1.3	0.7	93.3	95.3	2.7	2.0	1.3	1.3	1.4	0.7

From the Table 6 one can notice that the overall percentage of correctly answered question (the second option) on the post-test was 68.7 %. This value is close to the one needed to conclude that the tested concept is mastered. The test results for the second test item were excellent: over 90 % of student gave the correct answer both on the pre- and the post-test (Table 7).

One must note that the percentage of the fourth option in the first test item is remarkable, its value being higher than 20 %, which (on the basis of the criterion outlined above) points to a probable misconception. This test result and the discussion during interviews showed that certain misunderstandings are indeed present in the minds of the students. Looking at the test scores only, it might seem that most of the students were familiar with the ideas represented in the first two items. The interviews, however, showed that this was not quite the case. Actually, most of the students had difficulties in recognizing ionic substances and had problems in defining their entities. Actually, many students thought that *molecules* are present in solid sodium chloride and that ions are formed only when it is dissolved, the students, it seems, being convinced that all substances are built of molecules. They related the sodium chloride formula to the term "molecule" simply because the symbols Na and Cl were written together. Similar findings were reported in the literature (Levy Nahum et al., 2004; Taber, 2001; Tasker, 1998).

The following excerpts are representative of the erroneous belief of students that entities in ionic substances resemble covalent ones.

"*When it is not dissolved, molecules are present. In an aqueous solution ions are formed.*" (III-low achievers)

"R: *Are the NaCl entities in the solid substance molecules, ions or both?*

S: *Molecules.*

R: *Why do you think so?*

S: *There are no ionic properties when a substance is not in aqueous solution. When it is not dissolved it does not act as an ion.*" (III-middle achievers)

"S: *In solid substances only molecules are present.*

R: *Are there molecules when a substance is not in a solution?*

S: *Yes… When I think a little bit, if it is only a physical dissolving, then molecules will be present and they will be mixed with the water molecules.*

R: [reads the second question] *How do we know that these are ions?*

S: *They are charged.*

R: *But it does not say that they are in an aqueous solution.*

S: *It is not defined, but they are certainly ions.*" (IV-high achievers)

Some students claimed that NaCl reacts with water and NaOH and HCl are obtained. It is clear that these students could not distinguish between terms "react" and "dissolve" and between substances and particles. They stated: "*NaCl reacts with water and NaOH and HCl are present. The latter are molecules*." (III-high achievers). The same student when asked about NaCl entities said "*molecules, because there are no plus or minus signs*".

It could be mentioned that Naah & Sanger (2012) who identified and listed several misconceptions, among others the following one: "Ionic salts chemically react with water when dissolved *via* double displacement to form an acid and the metal oxide or hydroxide".

Some confusion was noticed regarding terms "element" and "elementary substance", as can be demonstrated by the following excerpt.

"S: *Well, the whole … NaCl … can exist as a molecule, but if we are talking about its entities – they can not.*

R: *What are its entities?*

S: *Sodium and chlorine*." (III-high achievers)

Item 3: The third test item was: "Instead of $3N_2$, in a chemical equation, you can write: a) NNNNNN; b) $2N_3$; c) 6N; d) any of the above; e) none of the above". Results are summarized in the following table.

The percentage of correct answers on the post-test is 71.3 %, which is satisfactory. Notably, "6N" was the most plausible answer for 22.7 % of students both on pre- and post-test. It seems likely that these students were only counting nitrogen atoms, without taking into consideration the meaning of symbolic representations. As mentioned earlier, a value higher than 20 %, suggests the presence of a misconception. Sadly, this value has not changed in the post-test, reinforcing the conclusion that some misconceptions are very persistent and hard to change.

Table 8. Percentage of chosen options to the third test item

		a		b		c		d		**e**		Other	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Year of study	I	0.0	4.0	2.0	4.0	18.0	16.0	8.0	0.0	72.0	76.0	0.0	0.0
	II	0.0	0.0	13.5	2.7	37.8	59.5	2.7	2.7	45.9	35.1	0.0	0.0
	III	0.0	0.0	3.0	0.0	12.1	3.0	12.1	3.0	72.7	90.9	0.0	3.0
	IV	3.3	0.0	3.3	0.0	23.3	10.0	3.3	0.0	63.3	86.7	3.3	3.3
	Total	0.7	1.3	5.3	2.0	22.7	22.7	6.7	1.3	64.0	71.3	0.7	1.3

Some main findings related to the erroneous notions of students drawn from the interview discussions regarding the third test item are: a) basically wrong generalizations are often made [examples: "*subscript 2 is present in non-metals*" (I-high achievers); "*subscript 2 is present in gases*" (IV-high achievers); "*subscript 2 is present in F, Cl, Br and I because these are in the same group*" (IV-middle achievers)]; b) elementary substance is not distinguished from element [examples: "*N_2 does not stand for elementary substance, but for two connected atoms, whereas elementary substance is marked as N*" (IV-middle achievers)]; c) atoms are not distinguished from molecules [examples: "*N_2 is the same as 2N because there is number 2 in both symbols*" (II-high achievers)] and d) statements were made that clearly point to gaps in knowledge [examples: "*subscript 2 shows valency of the element or its atomic number*" (III-low achievers)].

All such statements, whether being misconceptions or originating from a lack of knowledge, are important to deal with as they could lead to erroneous concepts during subsequent education.

Table 9. Percentage of chosen options to the fourth test item (the first part)

		a		**b**		Other	
		Pre	Post	Pre	Post	Pre	Post
Year of study	I	10.0	8.0	90.0	92.0	0.0	0.0
	II	2.7	0.0	97.3	100.0	0.0	0.0
	III	9.1	3.0	90.9	93.9	0.0	3.0
	IV	30.0	3.3	63.3	96.7	6.7	0.0
	Total	12.0	3.3	86.7	95.3	0.7	0.7

Item 4: The next item consisted of two parts and covered the process of burning and the criterion according to which certain change can be considered to be a chemical

reaction. We asked whether burning is a (a) physical or (b) chemical change (the first part of the question) and listed several reasons for this: a) the change is reversible; b) the change is irreversible; c) a phase change occurs (solid–liquid or solid–gas) and d) new substances are formed (the second part).

Table 10. Percentage of chosen options to the fourth test item (the second part)

		a		b		c		**d**		Other	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Year of study	I	2.0	2.0	12.0	68.0	26.0	10.0	56.0	10.0	4.0	10.0
	II	0.0	0.0	40.5	70.3	16.2	5.4	43.2	16.2	0.0	8.1
	III	3.0	3.0	24.2	24.2	21.2	21.2	48.5	48.5	3.0	3.0
	IV	0.0	0.0	30.0	33.3	20.0	3.3	33.3	56.7	16.7	6.7
	Total	1.3	0.7	25.3	54.7	21.3	7.3	46.7	28.7	5.3	8.6

This was the only item whose total outcome was negative. Actually, most of the students were able to distinguish between physical and chemical change but problems appeared while defining a criterion according to which a change will be classified as chemical. Difficulties in distinguishing physical and chemical changes and misunderstandings concerning a reaction of burning were registered in other studies, too (Driver et al., 1994; Kind, 2004).

Some doubts could be noticed in the answers of students on the test represented by choosing two options (in most cases, those were the options “b” and “d”). The distribution of chosen options in Table 10 clearly shows that the overall percentage of the second option is very high, especially that in the post-test. This is an apparent indicator of deep-rooted misconception. The notion that the physical changes are reversible and the chemical ones are irreversible was prevalent in many discussions. Nakhleh (1992) reported similar finding. She stated that some of the students seemed to think that only physical changes were reversible. Thus, to them, chemical changes were always seen as irreversible.

The following interview transcript excerpt from our study is just one example of existence of vague notions present in the minds of students.

“R: *You have answered that burning is a chemical change because it is irreversible. Is it possible that there are some reversible chemical changes?*

S: *Well … we have just talked about ketones. It was related to changing one thing into another and … Yes, I think that there are some reversible chemical changes.*

R: *So, why did you write that chemical changes are irreversible?*

S: *It means that the correct answer would be that new substances are formed. But, if new substances are indeed obtained, it would not be possible that the reaction is reversible. In reversible reactions new substances are not produced; the original substances would be obtained.*" (III-high achievers)

Item 5: In this study we have also included concepts of dissolution and crystallization, processes that, depending on the nature of substances involved, can be considered as physical or chemical changes (Kind, 2004; Nelson, 2003). Moreover, Nelson (2003) asserts that substances can undergo three kinds of change: physical, physicochemical and chemical, giving examples of dissolution both as physicochemical and chemical processes.

In our study, the item related to this concept was: "A substance soluble in water, after crystallization is: a) always identical with the original; b) sometimes identical with the original or c) never identical with the original". In addition, students were supposed to give a reason to support their claim. We did not point to any example of a substance in the test item, thus leaving this task to the students. However, two experiments dealing with NaCl and anhydrous $CuSO_4$ were carried out and discussed during the instruction. Either this activity was not enough to stimulate and motivate students or it was not performed in a plausible way but, in any case, the post-test results are only insignificantly better (Table 11).

One can notice a nearly equal distribution of the chosen options in the pre-test. If complete answers are considered (choosing a correct option and giving an acceptable explanation) the achievements were even poorer (18.6 % correct pre-test answers and 25.7 % for the post-test results).

Table 11. Percentage of chosen options to the fifth test item

		a		**b**		c		Other	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
Year of study	I	32.0	20.0	20.0	46.0	48.0	32.0	0.0	2.0
	II	37.8	59.5	32.4	21.6	27.0	18.9	2.7	0.0
	III	51.5	30.3	36.4	42.4	9.1	21.2	3.0	6.0
	IV	30.0	40.0	53.3	50.0	13.3	6.7	3.3	3.3
	Total	37.3	36.7	33.3	40.0	27.3	20.7	2.0	2.7

Some of the argumentations of students who had correctly answered the first part of the question were related to change in the phase, temperature or other external conditions. Surprisingly, the number of correct explanations of students who chose the correct option in the pre-test decreased in the post-test. A possible reason for this observation could be that students were aware that the test results will not affect their final grade and were, therefore, less attentive.

Those students who chose the first option usually gave explanations using the table salt as an example. A representative for these statements is the following one: "*There is always the same substance after the evaporation, because nothing else is added to the system*". (III-high achievers).

The opinions of those students who thought that the substance after evaporation will never be the same as the original one are also of interest. Some of their statements are given as an illustration: "*The substance has already undergone certain changes and can not be brought into the original form; new properties are added to it*" (I-middle achievers-pre); "*After the water evaporates, the salt is not the same*" (II-low achievers-post).

Part of students (irrespectively of age) claimed that the salt will evaporate along with the water. Sometimes, more "detailed" description was given, saying that "*If the substance is powdered, it will evaporate along with the water*" (I-low achievers-post). Similar notions were found in some earlier studies (Lee et al., 1993) in which students' ideas that sugar evaporates from water, disappears or change into liquid were identified.

Item 6: The final test item consisted of three sub-questions:

6a. Chemical reaction involving gases represent simple mixing.

6b. Chemical reaction must occur under certain external condition (such as heat, pressure …)

6c. Chemical reaction will continue until all reactants are exhausted.

Students were supposed to qualify the accuracy of the proposed answers and make comments. Only the distribution of correct answers is given for this item.

Table 12. Percentage of correct answers to the sixth test item

		6 a		6 b		6 c	
		Pre	Post	Pre	Post	Pre	Post
Year of study	I	32.0	14.0	21.0	42.0	24.5	25.0
	II	17.6	16.2	25.7	31.1	12.2	30.4
	III	22.7	43.9	39.4	31.8	32.6	30.3
	IV	16.4	29.3	62.1	48.3	30.2	50.9
	Total	23.3	24.2	34.2	38.3	24.3	32.6

These values in Table 12 are not encouraging, pointing out to the low extent to which concepts are mastered. Still, there were some very good answers and for this analysis we highlight one of those: "*In order to react, gases must be mixed, but by mixing them a reaction will not necessarily occur*" (I-high achievers-pre).

Some of the most common misconceptions that we have found and examples to support the findings are listed below.

Misconceptions	Examples
Gases are not miscible	*There are oxygen and nitrogen in the atmosphere. They are not miscible and there is no reaction.* (I-middle achievers)
Confusing "miscibility" and "bonding".	*Gases are not miscible because they are not bonded.* (I-middle achievers)
There is an instantaneous reaction when two gases are in contact.	*If hydrogen and oxygen are mixed, water will start to flow.* (IV-middle achievers)
Not distinguishing concepts of "reacting", "dissolving" and "melting".	*In some reactions, reactants can be in excess. For instance, dissolving sugar in small amount of water. However, there are reactions in which all reactants will be exhausted. Such is the case of wood burning.* (III-middle achievers) *The reaction is a physical change and as temperature rises, water passes from solid to liquid.* (I-high achievers)
An external condition must be applied for a chemical reaction to take place.	*In absence of external factor, a mixture is obtained.* (I-low achievers-pre) *An external influence is only needed if the reaction is endothermic.* (IV-high achievers-pre)
Chemical reaction will continue until all reactants are exhausted.	*It is not possible that only a certain number of reactants are exhausted. Reaction continues until all reactants are exhausted.* (I-middle achievers-pre) *Burning of ethyl alcohol is possible until the reactants are exhausted.* (II-high achievers-post) *One of the reactants will be exhausted if the other is a catalyst.* (III-low achievers)
Misconception regarding reversible reactions.	*If only one of the reactants is exhausted, a reversible reaction takes place.* (III-middle achievers) *At least one reactant needs to be exhausted or equilibrium is reached and the reaction stops.* (II-low achievers)

The origin of misconceptions can not be easily determined. Chemistry teachers (both present and former) and science textbooks are important factors in transferring knowledge to students. This process often leads to acquiring and understanding of various concepts, but in some cases may contribute to the appearance of misconceptions. Garkov (2006) argues that some problems may be associated with the lack of logical organization of the chemistry topics presented in the textbook and "bombarding" students with misunderstood concepts and foreign-sounding terms that are to be quickly memorized. Moreover, *prior knowledge* and *everyday experiences* undoubtedly plays a great role, both positive and negative, in the process of concept building.

Concepts that were objects of the present investigation are in general rather well elaborated in Macedonian textbooks. However, the authors of the study have found several imprecise interpretations in some textbooks that could be sources of misconceptions.

One of these is related to the inadequate usage of the term "molecule". Students, reading these textbooks, come across statements such as: "… formula units (KCl, NaCl, H_2SO_4 etc.) are considered as molecules in a broad sense" (Cvetković, 2002b, p. 26) and calotte model of "calcium oxide molecule" is given as typical example (Cvetković, 2002b, p. 19); "… the entire crystal represents a giant molecule" (Cvetković, 2002b, p. 135) or "Molecules of most substances (ice, table salt etc.) are regularly arranged" (Gešoski & Nonkulovski, 2009, p. 17). The use of calotte models in explaining structure of ionic substances by some secondary school teachers was also registered and pointed out.10)

Some erroneous interpretations regarding ideas of "element" and "elementary substance" and their distinction are, also, present in some textbooks. The following statement can serve as an example: "Molecules of elementary substances or elements consist of atoms of the same chemical element" (Gešoski & Nonkulovski, 2009, p. 13).

Dissolving a substance in water is usually considered as a physical change (Aleksovska, & Antonovska, 2010, p. 21; Cvetković, 2002a, p. 49). Sugar and table salt are the most common substances used as representatives in explaining this process. It is quite logical to do so when teaching beginners in chemistry, only these statements are too general and can mislead the students to believe that no exceptions are possible. A warning about the existence of exceptions would certainly be helpful.

Conclusions

Some common conclusions can be derived from this research about misconceptions concerning chemical reactions and symbolic representations. It was noticed that most of the students were not applying previously learned concepts and were able to give examples only within the latest material they have learned. Their statements were either too general or tightly related to a sole example. For instance, some students claimed that a reaction between two gases is always possible based on the experiment they have seen (reaction between hydrogen chloride and ammonia). It is likely that these generalizations will misguide students in the concept building process and can be a source to misconceptions.

Our idea of the questions proposed in the test and those asked during interviews was oriented to activating thinking of students and getting insight into their general knowledge and understanding of some basic chemistry concepts. The intervention program was aimed to facilitate understanding of concepts concerning chemical reactions among students of different levels of study. The higher scores in the post-test pointed out the improvements in achievement of students for all test items (with an exception of the fourth one) and showed that the intervention program was efficient in gaining more scientific explanations by students. Still, the post-test scores are not very high. Thus, one cannot conclude that the concepts are mastered by the majority of students.

A positive trend in the understanding of chemical reactions by students across the various levels of study was noticed, although it was not absolutely regular. Namely, the results from the second-year students contradicted the previous notion. Furthermore, the findings did not indicate a *big* difference in understanding of students of different age. Similar results are reported in the literature (Özmen, 2011).

The one-way ANOVA results indicated that the means of the four sub-samples were different. Additionally, the post hoc analysis found that mean differences were not statistically significant for the following pairs of sub-samples: pair 1 and 3 and pair 3 and 4 in the pre-test and pair 1 and 2 and pair 3 and 4 in the post-test, indicating similar concept mastering by the students from these samples.

The descriptive statistics regarding the comparison of the test results according to the gender suggested that the mean scores in the post-test was higher for female participants, but the *t*-test analysis indicated that those differences were not statistically significant. On the other hand, the enhancement in the test scores was found to be statistically significant for females, but not for males. It would certainly be advisable to test these findings by analyzing a larger sample.

The effect of interviews to the students' performance on the test was also investigated in this study. There were no significant differences between the two groups (interviewed and non-interviewed) of students in the pre-test (which was expected since the interviews were performed after the initial testing). However, the interviewed students outperformed the non-interviewed ones in the post-test. Moreover, the improvement of the interviewed students was found to be statistically significant.

One of the main objectives of this research was to detect misunderstandings and difficulties and to address some misconceptions present in the minds of high-school students. More than 15 misconceptions were registered, both by test and interview analysis. Many of them were less prevalent in the post-test, but there were still several deep-rooted misconceptions that remained (almost) unchanged after implementing the intervention program. Students had difficulties in many aspects, such as: identifying the entities of ionic substances (an opinion that there are always molecules in solid substances prevailed); defining a criterion according to which a change will be counted as chemical (most of the students considering the chemical reactions as irreversible); differentiating terms such as "miscibility" and "bonding" or "element" and "elementary substance"; distinguishing concepts of "reacting", "dissolving" and "melting" etc. Problems were also detected in the understanding of the symbolic representations of atoms and molecules, especially with respect to the meaning of subscripts and coefficients. Some misunderstandings were present about the process of crystallization and reactions involving a limiting reagent.

The test items, which were developed by the authors, can be used to repeat this research and compare the findings. Knowing that some of the tested misconceptions (and many more) are found in the literature, one may presume that some considerations derived from this study could be an important starting point for teachers to address potential misconceptions that *their students* might have. Whereas many chemical terms are abstract, molecular models and animations can be used by teachers to clarify certain phenomenon as has already been shown many times (e.g. Coll & Treagust, 2003; José & Williamson, 2005; Milne, 1999).

Caution in explanations and precise formulation of basic terms is also needed, especially when students make their very first chemistry steps (in the secondary school). Misconceptions can occur when students come for instruction holding meanings for everyday words that differ from the scientific meaning (Nakhleh, 1992). Everyday experiences (such as the observation of the process of burning) can interfere with the concepts learned in school, thus creating confusion in the minds of students since they can construct concepts in a non-scientific way and invoke these ideas in their subsequent learning, the novel concepts being related to the old (incorrect) ones, thus forming an unstable conceptual scheme in their minds. Some school-made misconceptions can be formed if inadequate explanations are offered to the students. One example of such kind of misconceptions that has been discussed in this paper is the usage of calotte models in explaining the structure of ionic substances.

One thing that might be missing in the chemistry teaching (not just in Macedonia but more generally) is the more extensive use of drawings, models and video-materials. Some of these materials can be found in the Macedonian textbooks and handbooks, but more important and useful would be those developed by teachers and students themselves. In that way, a better visualization and clarification of concepts will be attained, as well as active participation in learning process.

NOTES

1. http://www.scribd.com/doc/52664732/student-alternative-conceptions-in-chemistry
2. http://www.rsc.org/images/Misconceptions_update_tcm18-188603.pdf
3. http://www.abpischools.org.uk/page/modules/solids-liquids-gases/slg2.cfm?coSiteNavigation_allTopic=1
4. http://www.bbc.co.uk/schools/ks3bitesize/science/chemical_material_behaviour/behaviour_of_matter/activity.shtml
5. http://www.s-cool.co.uk/a-level/chemistry
6. http://www.s-cool.co.uk/gcse/chemistry/atomic-structure/revise-it/states-of-matter
7. http://www.s-cool.co.uk/gcse/chemistry/atomic-structure/revise-it/particles
8. http://www.jce.divched.org/JCEDLib/QBank/collection/CQandChP/CQs/ConceptsInventory/pConcepts_Inventory.html
9. http://www.arps.org/users/ms/pricen/one%20pagers/common_misconceptions%20chemistry.pdf
10. Aleksovska, S. Personal communication, 2011.

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