

Addressing Misconceptions about the Particulate Nature of Matter among Secondary-School and High-School Students in the Republic of Macedonia

Marina I. Stojanovska¹, Bojan T. Šoptrajanov², Vladimir M. Petruševski¹

¹Institute of Chemistry, Faculty of Natural Sciences and Mathematics, Ss. Cyril & Methodius University, Skopje, Macedonia

²Macedonian Academy of Sciences and Arts, Skopje, Macedonia
Email: marinam@pmf.ukim.mk

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A study was conducted to identify concepts about the particulate nature of matter among secondary- and high-school students ($N = 187$) and to address some misconceptions regarding this topic, especially the misunderstandings related to the vague ideas of the relationship between the macro and micro world. Data were collected using both quantitative (six-item multiple-choice instrument in a pre-test-post-test design) and qualitative (semi-structured focus group interviews) methods. Paired-samples *t*-test analysis showed that students experienced significantly higher results in the post-test when compared to the pre-test, thus confirming the efficiency of the intervention program in facilitating the understanding of some basic elements of the theory and practice concerning the particulate nature of matter (widely known as *particle theory concepts*, a term which will be used in this paper as well) among students of different levels of study. The findings revealed seven misconceptions prevalent by more than 20% of students and some additional ones emerged from the in-depth focus group discussions. The analysis of the content of textbooks indicated that some erroneous chemical concepts might have been formed as a result of the teaching of chemistry and that of physics, as well. The use of animations and molecular models had a positive effect on students and pointed to the need of introducing, in the chemistry teaching, the new material more visually.

Keywords: Focus Group Interviews; Intervention Program; Misconceptions; Particle Theory Concepts; Particulate Nature of Matter; Secondary- and High-School Chemistry Education

Introduction

Chemistry is a subject based on concepts, many of which are abstract and are therefore hard to grasp and learn especially when the students are put in a position to believe without seeing. On the other hand, students are basically familiar with a number of relevant concepts as a result of their previous learning (Roschelle, 1995). The potentially present preconceptions about the world itself can be reflected in the chemistry lessons and can sometimes grow into misconceptions.

It has been known that the misconceptions are powerful, extremely persistent and hard to change, creating obstacles to further learning (Canpolat, 2006; Pabuçcu & Geban, 2006). Many misconceptions concerning various chemistry (and science in general) topics have been documented (Horton, 2007; Kind, 2004). Also, many studies in the field of science misconceptions and difficulties in learning and understanding chemical concepts have been reported (Chiu, 2005; Cliff, 2009; Çalýk et al., 2005; Kariper, 2011; Levy Nahum et al., 2004; Morgil & Yörük, 2006; Taber, 2011; Wenning, 2008). In some of them, students' drawings or pictorial representations within the test item play an important role in inspecting their thinking (Mulford & Robinson, 2002; Nyachwaya et al., 2011; Onwu & Randal, 2006). The misconceptions related to the particulate nature of matter are perhaps some of the most investigated ones and are widely reported in literature (Badrian et al., 2011;

Banda et al., 2011; Bindernagel & Eilks, 2009; de Vos & Verdonk, 1996; Bridle & Yeziarski, 2011; Gabel & Samuel, 1987; Margel et al., 2004; Özmen & Kenan, 2007; Skamp, 2009; Yeziarski & Birk, 2006).

Many misconceptions are due to the fact that students do not distinguish between macroscopic and microscopic explanations (Bucat, 2004; Chandrasegaran et al., 2007; Meijer, 2011).

According to Johnstone (2000), the chemical knowledge is acquired at three levels: a) the *macro and tangible* (what can be seen, touched and smelt); b) the *sub-micro* (atoms, molecules, ions and structures); and c) the *representational* (symbols, formulae, equations, mathematical manipulation, graphs etc.) and the links between these levels should be explicitly taught. None of the above aspects is superior to another; on the contrary, they complement each other. Aware of the conflict between the intuitive, continuous model and the "scientific", particulate one, Ben-Zvi et al. (1986) pose the question: "Is an atom of copper malleable?" In their study, involving students from all levels, Treagust et al. (2011) display the widely-held confusion between the macroscopic and sub-microscopic properties of matter held by the students. Namely, the authors highlight the ideas of students that particles (sub-microscopic representation) themselves are compressed and pushed closer together instead of the gas being compressed (macroscopic representation).

Introducing all three levels to students *simultaneously* leads to an "overload of their working memory space" (Sirhan, 2007)

and can be a potential reason for misconceptions to emerge. Furthermore, the process of going directly from the macroscopic to the symbolic level, neglecting the sub-microscopic one, may also be responsible for the appearance of misconceptions. Therefore, chemistry concepts must be taught progressively, stepwise, starting with macroscopic observation and only then go to the microscopic interpretations.

Misconceptions that stem from the teaching process are referred to as *school-made misconceptions* (Barke et al., 2009). Perhaps the most resistant to change are the misconceptions that students build in the early stages of their development. Some of the reasons for their occurrence could be traced to problems of the specific terminology and used wording, especially when introducing the concepts of substances, the particles of which they consist and chemical symbols used for their representation. Taber (2001) argues that definitions of most fundamental concepts are problematic. Similarly, Nelson (2003) stresses that many basic chemistry concepts are difficult to teach because “the definitions of these concepts given in textbooks either lack precision, or invoke ideas that beginners are not familiar with, and have to accept on trust”.

In this respect, the situation in many Macedonian textbooks (for both secondary schools and high schools) is not very different. Thus, statements can be found in which a *substance* reacts with one or more *particles* (atoms, molecules, ions ...), such as: “An acid is any substance (molecule, anion or cation) capable, during chemical reaction, to give a proton to another substance.” (Cvetković, 2002b: p. 191), “By accepting a proton, the former base becomes an acid.” (Šoptrajanov, 2002b: p. 74). Similar (basically incorrect) notions are present in statements such as: “When forming ionic compounds, iron gives three electrons.” (Aleksovska & Antonovska, 2010: p. 142), “The elementary substance phosphorus consists of four atoms of element phosphorus.” (Aleksovska & Antonovska, 2010: p. 39), “... glycerol has three hydroxyl groups ...” (Aleksovska & Stojanovski, 2003: p. 176), “Deoxyribonucleic acids are macromolecules.” (Aleksovska & Stojanovski, 2005: p. 112) etc.

All of the above statements may be at the origin of formation of new misconceptions or strengthening already existing ones. Students holding deep-rooted misconceptions often construct new knowledge on a faulty basis to which further mental connections are made. Many students (and some of their teachers, too) believe that their adopted concepts are correct because they *make sense* and fit within their previously established mental framework. Faced with new information that differs from their established conception, a cognitive conflict arises (Demircioğlu, 2009), the students being put in a position to either change their rather naive view into a scientifically accepted one (for this to happen, a conceptual change must be developed first) or, otherwise, to reject or ignore this new information simply because *it seems wrong*. Active experimenting, use of animations and multi-frame illustrations (and even drawings) could help achieve this cognitive transformation (Kabapinar, 2009). It is of utmost importance to identify the misconceptions of students, using diagnostic tests, confront the erroneous notions applying appropriate intervention program(s) expecting that the misconceptions will eventually be eliminated, corrected and replaced with ones that are correct and stable.

Regarding the chemistry in Macedonia, only few investigations have been conducted so far that address the misconceptions present among students (Monković et al., 2007; Stojanovska et al., 2012a; Stojanovska et al., 2012b, Petruševski et

al., 2006; Petruševski et al., 2007). A need for a more thorough study of misconceptions in chemistry necessarily emerged. As a consequence, the present study was planned to investigate the potential misconceptions associated with the particulate nature of matter among secondary- and high-school students in Macedonia. It focuses on in-depth understanding of concepts held by students and on the implementation of an instructional program aimed to help students in overcoming erroneous concepts they have. The results from the multiple-choice item testing and focus group discussions are summarized in the present paper.

Objectives of the Study

One of the objectives of this study was to check the capability of students to transfer their knowledge through the three levels of thinking as well as the ability to explain physical and chemical properties mostly in terms of macro- and microscopic approaches. At the same time, the study was intended to investigate the views of the students about the appearance and properties of substances, on one hand, and the entities they consist of, on the other, and to address potentially present misconceptions about the particulate nature of matter.

The study was conducted to evaluate the effectiveness of intervention program on cognitive achievement towards particle theory concepts of eighth-grade and high-school students. The intervention program (that included deepened explanations, molecular models, experiments, discussions and web animations) complemented with interviewing students was implemented during instruction to facilitate understanding of particle theory concepts among students and to attempt to eliminate some of the misconceptions found.

The null hypothesis was tested at the 0.05 significance level and was formulated as:

H_0 : There is no significant difference between the pre-test and the post-test results.

The investigation was guided by the following *research questions*:

- 1) Does the intervention program improve the achievement of the students in the post-test?
- 2) Are there any trends in understanding the particle theory concepts by the students across the various levels of study?
- 3) What are the misconceptions present in the students' thinking regarding some issues on the particulate nature of matter?

Methodology

Design

The study consisted of two parts: implementation of six-item multiple-choice instrument in a pre-test-post-test design (quantitative approach) and realization of focus group interviews (qualitative approach). It involved the evaluation of an instructional program in assessing the understanding of students about concepts associated to particulate nature of matter. The conceptual change intervention concerning the three levels of understanding consisted of active learning, including interactive lectures using animations (BBC, 2012; Gregorius, n.d.), experiments and discussions. We deemed the animations could be helpful in visualizing atoms and molecules, their sizes and their movement in a particular phase of a substance, as well as the phase changes of the substance in question. Additional animations were found together with the students.

The experiments carried out in front of (or together with) the students followed by discussions were:

- a) Freezing of water in a plastic cup and discussing phase changes from the macro and micro points of view;
- b) Burning of ethanol and discussing the fate of the C, H and O atoms and;
- c) Dissolving anhydrous copper(II) sulfate in water, evaporating the solvent and comparing the chemical nature of the substance(s) before and after the change.

The developmental stages of the investigation are briefly stated as follows:

- 1) Administration of the pre-test;
- 2) Analysis of the pre-test data using the software package PASW 18.0;
- 3) Recording misconceptions and identifying students holding those misconceptions;
- 4) Conducting focus group interviews;
- 5) Preparing transcripts and analyzing each interview;
- 6) Implementation of instruction program;
- 7) Administration of the post-test (two weeks after finishing the stage 6);
- 8) Analysis of the post-test data using the software package PASW 18.0.

Sample

The instrument was administered to a total of 187 sample students both from a secondary school ($N = 30$) and from several high schools ($N = 157$) in the 2011/12 school year. Further, in order to get an insight into the particle theory concepts among students of different age and the related misconceptions, four sub-samples were formed according to the level of study in which students were enrolled. Regarding the sampling, it is mentioned (Hoque et al., 2011) that the minimum number of subjects for experimental research is 30. Thus, the number of students involved in this study was sufficient for further analysis.

A total of 77 participants were purposively selected from the sample students to take part in the group discussions. According to their earlier performance in chemistry, students were categorized into two sub-groups (high achievers and low achievers). Details concerning the participants involved in the study are given in **Table 1**.

During the focus group interviews, mutual respect and confidentiality was observed. The participants (students) were carefully explained that the test results and interview discussions would be used for research purposes only and that all information would be kept confidential. For that reason, each student was assigned a code (S1, S2 etc.) in the data analysis

process. Teachers approved the testing and interviewing students. Students who agreed to participate in focus group discussions had the right to withdraw at any given moment and were guaranteed that the research will not affect their grade.

Data Collection

A combination of quantitative and qualitative data collection techniques was used and two kinds of instruments were implemented: multiple-choice concept tests and focus group interviews. The usage of both kinds of methods led to an improvement of the validity of results by means of triangulation (Husein, 2009; Jick, 1979). The advantages of the written test are that it is easily administered to a wider population and that it allows calculating the percentages of correct and incorrect answers (Schmidt et al., 2003), thus enabling to draw conclusions about the most prevalent choices that can indicate existence of a misconception. Nevertheless, in many cases students who hold misconceptions were able to give correct answers to open-ended questions, especially to those that do not seek higher mental activation. Therefore, it is advisable to use misconceptions as distractors in a multiple-choice test (Herrmann Abell & DeBoer, 2011) and, in that way, to provide students with plausible answer choices to select from, so they are less likely to simply guess the correct answer. Furthermore, interviews are an appropriate technique when looking for in-depth explanations. Interviews, both individual (Singh, 2008; Sözbilir et al., 2010) and in a group (Eybe & Schmidt, 2004; Muzaffar et al., 2011; Nair & Ngang, 2012; Osborne & Collins, 2001) have been successfully used as data collection instruments in educational studies, the focus groups providing a possibility for interaction and exchanging ideas among participants.

Concept test: To identify notions that are present and to get insight into the misconceptions regarding the particulate nature of matter, a concept test was given both before and after group discussions and intervention program (these are referred to as pre-test and post-test respectively). The test was distributed to secondary- and high-school students (**Appendix 1**). It was conducted under normal class conditions and was completed within 40 minutes. It consisted of 6 items written in a multiple-choice format. No open-ended questions were provided for testing because students (a part of them) were later interviewed in a group, although occasionally an option existed to write down their answers if the participants thought this would be more appropriate. The test items were developed by the authors. Some of the misconceptions known in the literature were added as distractors (Horton, 2007; Kind, 2004; Anonymous, 2003; Yeziarski & Birk, 2006).

Focus group interviews: In this study, thirteen semi-struct-

Table 1.
Information on participants involved in the study.

Level of study		Number of participants		Number of focus groups	
		<i>N</i> (%)	High-achievers	Low-achievers	
Secondary school	VIII Grade	30 (16)	2	1	
	II Year	57 (31)	1	1	
High school	III Year	51 (27)	2	2	
	IV Year	49 (26)	2	2	
	Total	187 (100)			13

tured in-depth focus group interviews were conducted: three with secondary-school and ten with high-school students. The number of students in each group varied between 5 and 7 and the time needed for completing an interview was in the range of 40 to 90 minutes. The interviews took place in an empty classroom (or a laboratory) to enable uninterrupted conversation. They were audio-taped and transcripts were made for each focus group discussion.

The interviews were carried out according to the design proposed by Kvale (1996). They consisted of three phases: the *briefing phase*, the *main phase* and the *debriefing phase*. In the main phase students were asked questions (in an open-ended format) according to an interview guide prepared beforehand. Details about the interview protocol are given in the **Appendix 2**. The misconceptions identified from the tests were used as a starting point in the preparation of the interview guide and conducting the interviews themselves. More questions emerged during discussions depending on the answers of the participants.

Data analysis

In the concept test, each correct response was scored 1 point and each incorrect one - 0 points, thus making the maximum possible score on the test 6 points. Next, responses were analyzed using the Predictive Analytics Software PASW 18.0 and were subjected to mean, standard deviations and significance testing. In order to determine whether significance differences were present between the pre- and post-test, a paired-sample *t*-test was run.

Besides calculating the percentage of correct answers, the number of wrong ones that were present in the answers by approximately 20% or above was considered. Namely, according to Dhindsa & Treagust (2009), the incorrect responses (distractors) by more than 20% of the students indicate the presence of misconception of the tested concepts. The above-mentioned authors also proposed a criterion for satisfactory understanding the tested concept in a four-distractors-item, according to which it is necessary that at least 75% of the students give correct answers.

In the present study, students preferred one or two distractors for certain items. The misconceptions that were identified in the answers of over 20% of the students are reported in the Results section. The focus group interviews were not subject to a detailed analysis and are used as representative for misconceptions found in the written responses of the students. All interviews were conducted in Macedonian, so the excerpts quoted in this paper were translated into English.

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

Level of study	Pre-test			Post-test		<i>t</i>	Cohen's <i>d</i>
	<i>N</i>	Mean	SD	Mean	SD		
VIII	30	1.38	0.84	2.95	0.63	9.88*	2.11
II	57	1.29	0.97	4.32	1.44	14.60*	2.47
III	51	2.27	1.47	4.06	1.19	10.43*	1.34
IV	49	2.1	1.25	3.76	1.05	11.00*	1.44
Total	187	1.78	1.25	3.88	1.25	20.58*	1.68

* $p < 0.01$.

Results

The first research question was related to the effectiveness of the intervention program on the improvement of the students' achievement in the post-test. The comparison of the mean scores of pre- and post-tests showed that an improvement in cognitive achievement was evident (**Figure 1**), the positive results being found for all sub-samples in the study. The results of the paired-samples *t*-test analysis showed that that students experienced significantly higher results in the post-test when compared to the pre-test in each of the four sub-samples and in the total sample (**Table 2**) which indicates that the intervention program was efficient in improving the students' knowledge and understanding of particle theory concepts. Thus, the null hypothesis was rejected.

In addition, the effect size (Cohen's *d*) was calculated as a measure of strength of the difference between the pre- and post-test mean scores. The effect size values in **Table 2** are high ($d > 0.8$) implying relatively large mean differences for each sub-sample and for the total sample, as well.

With respect to the second research question for the trends in understanding of particle theory concepts by students across the various levels of study, one can notice that the *t*-values increase from eighth-grade to the fourth year high-school students' samples; the second value disagrees with this trend by being higher (cf. **Table 2**).

As a rough estimate of the concept-grasping by the students, the percentage of correct answers (both in the pre-test and the post-test) for all test items are given in the **Table 3**. The data summarized in this table show that in all cases but one (for eighth-grade students), an improvement in understanding can be observed. Students had problems solving items 1, 4 and 6 and understanding the concepts involved, but were more successful at answering the other items in the pre-test.

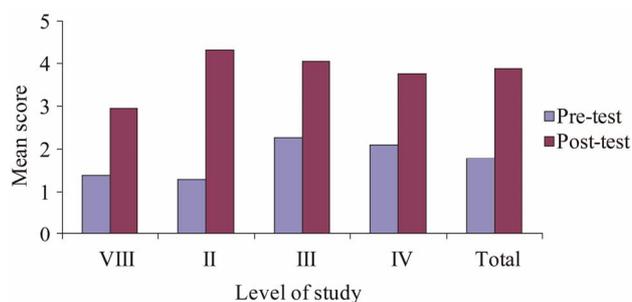


Figure 1. Comparison of the pre-test—post-test mean scores.

As for the third research question, some distractors were favoured for certain items in the test and thus seven misconceptions were identified in the answers given by students. Several more misconceptions emerged on analyzing the interview transcripts. The misconceptions found in the written responses are listed here and are discussed in more detail in the next section. Percentages of students holding the particular misconceptions were also calculated (according the level of study, as well as the total sample percentage) and are summarized in the **Table 4**. No strict regularity in their appearance in different sub-sample students can be detected from the percentages of the prevalent misconception represented in the table. Misconceptions (M) identified through the written responses of the students were:

M1: Butadiene reacts with two bromines.

M2: Butadiene reacts with one molecule of bromine.

M3: Copper(II) sulfate from aqueous solution crystallizes as a solid substance composed of copper(II) sulfate molecules.

M4: In a process of ice melting, the volume of the system (mixture of ice and liquid water) increases.

M5: Particles change from solid to liquid ones.

M6: When ethanol is ignited, carbon, hydrogen and oxygen atoms (of which ethanol is composed), will ignite too and will burn just like the ethanol.

M7: The particles of a substance enlarge during heating that substance.

Three more misconceptions were detected in the test answers of certain sub-samples. Thus, among eighth-grade students, a notion that particles receive heat and enlarge was prevalent. In the pre-test, 33.3% of students have chosen this option. The percentage was not much reduced in the post-test (26.7%), underlining the fact that misconceptions are very resistant and hard to change. Two other misconceptions were observed in the

second-year high-school sub-sample analysis. A statement commonly present among such students was that carbon, hydrogen and oxygen atoms (of which ethanol is composed), will disappear when ethanol is ignited (31.6% in the pre-test and 7.0% in the post-test). Another favored distractor that represented a misconception was the one about particles of a substance shrinking during heating that substance. The percentage of students that held this erroneous notion prior to instruction was 28.1% and it was decreased to a great extent after the instruction (3.5% of students have chosen this option in the post-test).

Discussion

The overall findings resulting from this research were positive and suggested that the intervention program effectively contributed to the improvement in the knowledge of students and their understanding of particle theory concepts. The considerable increase in the post-test scores evidently supports this observation. However, several misconceptions were still present in the post-test. Some students, perhaps due to their poor understanding, might have been misled by the distractors. Misleading role of distractors was, presumably, the most pronounced in the eighth-grade sample, whose participants (by being the youngest) have limited knowledge. Also, beginners in learning chemistry might not have well developed chemistry concepts nor experience in chemistry and this could be assigned to the constant level of misconception for certain test items for eighth graders. Such was the case for the misconceptions referred as M1 and M2. These were distractors for the same test item. It is likely students who were doubtful in answering this test item have preferred the M1 in the post-test instead of their

Table 3.
Percentage of correct responses of students on pre- and post-test.

Item No.	VIII		II		III		IV		Total	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	10	13.3	8.8	47.4	0	51	0	49	4.3	43.3
2	63.3	96.7	29.8	82.5	52.9	92.2	44.9	89.8	45.5	89.3
3	53.3	16.7	40.4	80.7	52.9	66.7	40.8	42.9	46	56.7
4	10	26.7	3.5	56.1	5.9	31.4	8.2	42.9	6.4	41.2
5	23.3	80	29.8	71.9	76.5	88.2	73.5	95.9	52.9	84
6	10	83.3	15.8	87.7	47.1	72.5	40.8	55.1	29.9	74.3

Table 4.
Percentage of misconceptions present in each of the sub-samples and the total sample.

Misconception No.	VIII		II		III		IV		Total	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
M1	36.7	30	54.4	15.8	15.7	19.6	2	22.4	27.3	20.9
M2	40	56.7	29.8	28.1	72.5	27.5	98	28.6	61	32.6
M3	26.7	3.3	49.1	5.3	19.6	3.9	40.8	6.1	35.3	4.8
M4	40	83.3	42.1	12.3	31.4	15.7	44.9	26.5	39.6	28.3
M5	33.3	30	49.1	19.3	43.1	13.7	69.4	22.4	50.3	20.3
M6	36.7	10	31.6	17.5	21.6	9.8	18.4	0	26.2	9.6
M7	76.7	6.7	49.1	5.3	35.3	15.7	51	32.7	50.3	15.5

previously chosen option in the pre-test (M2) or the correct answer (option “c”). Furthermore, data in **Table 4** indicate that about 28% of the third- and the fourth-year students showed consistency in their answer regarding the first item (unfortunately, the wrong one) by choosing the M2 in the post-test. On the other hand, approximately 50% of each of these sub-sample students (cf. **Table 3**) experienced positive gain in respect to the tested concept on the first item (note that the percentage of correct responses for the third- and the fourth-year students is 0.0% in the pre-test), thus reducing the level of both M1 and M2 in the post-test. This was not the case with the eighth-grade students.

Another observation is interesting to note at this point. It was perceived that percent distribution for chosen test options was more or less equally represented for eighth-grade students, thus lowering the percent of correct answer for account of other distractors (which were potential misconceptions). To justify this fact two examples are pointed out. It was mentioned in the Result Section that 33.3% of eighth-grade students in the pre-test and 26.7% in the post-test have chosen the option that particles receive heat and enlarge (option “f” in the fourth test item). The percent of chosen option “f” was 3.9% and 0.0% for the third-year students and 2.0% and 0.0% for the fourth-year ones in the pre- and post-test respectively. This could explain the more pronounced level of M5 in the pre-test for students enrolled in higher grades. The second example refers to the first test item. It was noticed that 10.0% of eighth-grade students thought that the statement “one gram butadiene reacts with one gram bromine” correctly describes the equation. None of the third- or the fourth-year students has chosen this option.

It is fair to mention that, when dealing with multiple-choice items, students have an opportunity to guess the correct answer or, on the contrary, to be misled by the distractors. For this reason, the interviews were an important part of the research. During the focus group discussions, students tried to explain the statements they have chosen (or written) and, thus, helped the researchers involved in this investigation to understand the reasoning behind their opinions. Excerpts from the interview transcripts that are presented in the paper could enable readers to examine the trustworthiness of the research procedure.

The warm-up questions in the focus group discussions were aimed at the (mental) images that students had about atoms and molecules. On the basis of the experience in the microscopic world, an opinion that atoms and molecules are spherical prevailed as most of students recalled the illustrations they have seen in textbooks or models that they have been using earlier.

Further, considering the phase changes, some students referred to molecular distances and molecular forces as factors responsible for the change. Unfortunately, notions that molecules of liquid (or gaseous) water weigh less than the molecules of ice (or liquid water), that molecules can expand and stretch when a substance is heated and that the particles (atoms and molecules) can change their shape seem to be widespread even among students that do not fall in the category of low achievers.

Here, an emphasis is given to those misconceptions found in the written responses of students that were represented by more than 20% (the list of such misconceptions was given in the Results Section but in this part they are reviewed in more detail). In addition, excerpts from the conversations between the researcher (R) and student (S) are given to support the findings from the test analysis. After every excerpt a brief description is given that includes the type of school (SS or HS for secondary

and high school respectively), the level of education within the school in question (given by Roman numerals) and the subgroup to which the student belongs.

M1 and M2: Butadiene reacts with two bromines or with one molecule of bromine.

These two misconceptions were among the most persistent ones. The corresponding distractors were present with more than 20% in the pre-test (see **Table 4**) and even in the post-test, although the percentage of students who gave such answers decreased from 27.3 to 20.9% for the first and from 61.0 to 32.6% for the second option. Therefore, they can be considered to reflect potential misconceptions (M1 and M2). Although some improvement was obvious, the percentage of students holding erroneous views was still high, pointing once again to the general property of misconceptions: lots of efforts are needed to eliminate them and to engrave correct knowledge in the minds of the students.

During the focus group discussion, students, for example, explained: “*I have calculated correctly: there are two atoms of bromine and that is why butadiene reacts with two atoms of bromine.*” (SS-VIII-high achievers) or “*I considered that Br₂ is one molecule of bromine, so my answer is that butadiene reacts with one molecule of bromine.*” (HS-II-low achievers)

These excerpts clearly point out to the vagueness of the ideas of students and their inability to properly use the macro and micro concepts and the corresponding terminology. Surely, a substance **can not** react with only one or a few particles.

M3: Copper(II) sulfate from aqueous solution crystallizes as a solid substance composed of copper(II) sulfate molecules.

The second item of the test covers the concept of crystallization of copper(II) sulfate from aqueous solution and the offered options were: with five molecules of water; as a solid substance composed of copper(II) sulfate molecules; as a pentahydrate; as an anhydrous salt. We assumed that the first distractor would be an option of choice for the majority of students, but, instead, it turned out that such was the case with the second distractor (M3). The first option was chosen by less than 20% of the students in the pre-test and the second one with 35.3%. This indicates that most of the students have heard about crystalline hydrates and can recognize the formula of blue vitriol, thus connecting it with the term pentahydrate.

Sometimes erroneous notions are not perceptible right away and can be discovered only when looking at the in-depth responses. The next dialog is representative of that.

R: “S12, what is your opinion? You have answered that copper(II) sulphate crystallizes as pentahydrate from water solutions. Why do you think this is the correct answer?”

S12: “Last year we learned that ... er ... copper sulphate has five water molecules.”

R: “Where? Five water molecules in ...?”

S12: “In its structure.” (SS-VIII-high achievers)

Discussing within certain groups, some students claimed that CuSO₄·5H₂O can be formed if five drops of water are added to CuSO₄. It seems likely that for these students five drops are equivalent to five molecules (or five moles, perhaps?). In relation to this, Tasker (1998) warns about misleading molecular animations available as CD supplements to some textbooks, thus generating deeply embedded misconceptions such as the one that assert presence of only a few ionic species in a drop of water.

The presence of another very important misconception be-

comes apparent from the second item analysis. Namely, the above mentioned high value of 35.3% strongly indicates that students fail to distinguish ionic from covalent substances, so they refer to all building particles as molecules. It seems that this type of misconception is widely spread.

R: "Do you think that molecules of copper(II) sulfate exist?"

S10: "Yes."

R: "Could you explain in more detail what do you mean?"

S10: "I don't know ... I'm not sure."

S9: "I think that molecules of copper(II) sulfate do not exist because copper(II) sulfate is a compound."

R: "What about water? Is water a compound?"

S9: "Well ... yes."

R: "Does it consist of molecules?"

S9: "Yes, it does."

R: "When is it right to say "molecules"?"

S12: "When we talk about ions, it must be an ionic bonded compound." (HS-II-high achievers)

One possible reason for such a wrong concept can be found in some textbooks (Cvetković, 2002b: p. 33) where the author represents structural formulae of ionic compounds in the same way as those of the covalent ones, with a line between symbols of atoms implying the existence of mutual electron pairs. Many teachers apparently accept this scheme and make ball-and-stick models for every entity of every substance, including the ionic ones (Aleksavska, 2011). In this way, they create a distorted picture in the minds of their students and such a picture lasts for a very long time (in many cases, we dare say, it is a lifelong misconception).

There are some definitions of crystalline hydrates (Aleksavska & Antonovska, 2010: p. 130) that use both macro and micro viewpoints. The above textbook defines crystalline hydrates as: "A large number of salts obtained from aqueous solutions, in their structure, contain one or more molecules of water. These salts are called crystalline hydrates." Obviously, if such definitions are encountered in the very early stages of the chemistry (or science) education, they might have harmful consequences and make difficult the discrimination between **substances** and their **building blocks** (particles).

M4: In a process of ice melting, the volume of the system (mixture of ice and liquid water) increases and M5: Particles change from solid to liquid ones.

The most common misconceptions were those that reflected ideas about the dimensions and shape of molecules when the substance undergoes a phase change or any other change provoked by the changes in temperature or pressure. We tried to gauge the opinions that students have concerning very familiar phenomena: ice melting and freezing of liquid water.

The total percentage of the incorrect answer (M4) decreases in the post-test (cf. **Table 4**), as one should expect. However, the scores of the eighth-grade students are not in agreement with the overall outcome (the reasons for this finding are not quite clear, but one could speculate that, being the youngest group, their overall chemical knowledge is restricted).

To make items 3 and 4 more understandable, the researcher and students discussed (through interviews and instruction) about many everyday examples, such as the lakes freezing on the surface, the density of ice cubes, the bursting of plastic water-filled bottles when put in deep-freeze, the rock breaking due to freezing of water inside the gaps etc. It was found (Demircioğlu et al., 2005) that when chemistry concepts were related to everyday life during teaching, their retention in the

learner's mind was greater. On the other hand, Oloruntegbe et al. (2010) reported that students could not relate science concept learnt in school to home activities.

During focus group discussions, most students, explaining the ice melting, recalled their everyday experiences but the offered explanations were not always the scientifically accepted ones: "My answer is that particles change from solid to liquid ones. For example, if we put ice cubes in a drink, after some time they will melt and turn to liquid state. According to this, I thought that this answer is the most appropriate." (SS-VIII-high achievers)

The responses of students about changing the "state" of the particles are reported in the literature (Griffiths & Preston, 1992). In his study, Taber (2001) claims that it is common for learners to make statements such as: "The substance melt because its molecules melt."

As indicated before, 33.3% of secondary (eighth-grade) school students thought that particles receive heat and change their size. This view was clearly shown in the following excerpts from one of the secondary school groups' discussion: "An ice cube ... when exposed to sunlight and heat, starts to melt and its particles broaden." (SS-VIII-low achievers) or "I think that particles in ice are smaller than those in water ... and when ice begins to melt, the volume decreases." (SS-VIII-low achievers)

M6: When ethanol is ignited, carbon, hydrogen and oxygen atoms, of which ethanol is composed, will ignite too and will burn just like the ethanol.

The fifth item on the test deals with the nature of atoms in a chemical reaction. As an example of chemical reaction we considered the combustion of ethanol. The concept of burning or combustion of certain substances can be found in the eighth-grade curriculum, and in the subsequent education it is studied in more details. Explanations about reactions such as burning of magnesium, ethyne or ethanol as well as the chemical equations for the corresponding reactions can be found in many textbooks. One should, therefore, expect that students will be able to write down a chemical equation for this reaction and give a proper explanation. It was found, however, that students hold both tested misconceptions: (a) 26.2% of 187 students thought that atoms may be ignited and burned (M6) and (b) 14.4% thought that atoms disappear during chemical reactions. The latter was found to be the most prevalent option in the second-year high-school sub-sample.

However, during interviewing we could notice some failures in knowledge and vagueness about the students' perceptions about atoms. These are illustrated below.

R: "Why do you think that atoms will burn?"

S15: "Well, because ethanol has oxygen in its structure and it is able to burn." (SS-VIII-high achievers)

Some other type of misconceptions regarding the phase changes and the size of the particles were also documented. Some students believed that the particle size must be changed, while others failed in distinguishing between physical and chemical change. Here are comments of the students regarding these issues.

R: "What will happen with the particles when a substance is ignited?"

S21: "They change their phase."

S22: "I stick to my opinion that they will either increase their size or decrease it, because when they undergo a phase transition their shape will be changed. They must be changed; they

can not stay the same. In such a case, there will be no chemical change, nor will a phase transformation occur.” (HS-III-low achievers)

S3: “They will get into some other substances because ethanol passes from liquid to gas during burning.”

S17: “Since molecular space is changing as a result of burning, their size must change, too.” (HS-III-high achievers)

The findings show that some of the students retained their misconception, although they were faced with opposing opinions during focus group discussions.

M7: The particles of a substance enlarge during heating that substance.

This distractor was once again used to test the consistence in opinion of students concerning the size of the particles when the substance is heated. Several interesting (but not scientifically correct) opinions are presented to support the presence of this misconception.

S11: “I think that ... when water evaporates, molecules spread out because of the temperature ... they are heated. I think they enlarge.” (SS-VIII-high achievers)

R: “Will the molecule of water at 80 C be smaller, bigger or equally large to the one of water at 20 C?”

S11: “I think that when temperature changes, particle size decreases.” (HS-II-high achievers)

S70: “When heating an object, particles become wider.” (HS-IV-high achievers)

S8: “When heat gets inside the particles, they are heated and, due to that, increase their size.” (SS-VIII-low achievers)

On the other hand, some students claimed that molecules of ice are bigger than those of liquid water, in consideration of the fact that the volume of ice is bigger when compared to that of the same amount of liquid water.

R: “You said that freezing will make the water molecule larger. Could you explain what did you mean?”

S2: “Well ... the volume of ice ... water in the solid state is larger.”

R: “Do you think that if the volume is larger, the molecule must be larger, too?”

S2: “That’s right.” (HS-II-low achievers)

Several more categories of erroneous notions were registered during the focus group discussions. Fortunately, those were not widely spread among students. Some of them are the following ones:

S29: “Molecules that evaporate are lighter and go upward and the ones that stay in the vessel are heavier.” (HS-III-low achievers)

S32: [When water evaporates] “a vapor is formed and water molecules are decomposed into hydrogen and oxygen.” (HS-III-low achievers)

There was a good attempt by some students to give correct explanation in line with the fact that in many chemistry textbooks used in Macedonia (Cvetković, 2002b: p. 130; Šoptrajanov, 2002a: p. 113; Šoptrajanov, 2002b: p. 62) a number of illustrations indicate that when a substance changes its phase, the space/distance between particles is changing, not the particles themselves. On the other hand, some less precise statements can also be found. One of them is the following: “Because of that, molecules in a liquid can not substantially move apart from one another and turn into vapor” (Cvetković, 2002b: p. 132) indicating that *molecules* can turn into a gaseous state.

Similar findings are reported in the literature (Tatar, 2011). According to Taber (2001), the students have represented the

longest O-H bond in water molecule in the gaseous state of the substance, explaining the “fact” that the rise of the volume (due to the phase change) implies increasing the size of the molecule itself. Other studies (Mayer, 2011; Regan et al., 2011) notify that, when asked about water evaporation, most of the students have chosen the drawing according to which the water molecules separate into hydrogen and oxygen atoms.

At the end of the focus group discussion, as a conclusion, the following question was asked: “Will the particles (atoms, molecules or ions) possess similar properties as the parent material?” There were different ideas coming from students, but some improvements in thinking regarding their earlier standpoints were noticeable (see below).

S14: “It is my opinion ... that this statement is true. It is said in chemistry textbooks ... that the atom is the smallest particle that possesses the same physical and chemical properties as the substance it originates from.” (HS-III-high achievers)

S2: “Well ... because we are dealing with one substance, I think that the atoms will have the same physical and chemical properties ... because substances are made up of particles.” (SS-VIII-high achievers)

S5: “Atoms and all the other particles of which the substances are composed do not have the same properties as compounds have, because ... properties of that particular element or compound are added to the atoms.” (SS-VIII-high achievers)

S50: “In my opinion, molecules do not change, only substances change their state.” (HS-III-high achievers)

S64: “Physical properties are not the same. For example, we can see and touch sulfur, but not its atoms. So, atoms and molecules of sulfur as a whole constitute one object that has different properties from those characteristic of atoms and molecules themselves.” (HS-IV-high achievers)

It is likely that some erroneous concepts are formed in the teaching of physics, as well since imprecise definitions present in some physics textbooks can also lead to appearance of misconceptions that are evident in testing of chemistry concepts. Namely, according to Gešoski & Nonkulovski (2009) “All substances are composed of small invisible particles that possess the same properties as the parent material. These particles are called molecules.” With respect to the atom, the authors have written: “The atom is the smallest particle of a chemical element that retains its physico-chemical properties.” In fact, an analogous statement is found in the chemistry textbook for 7th grade (Cvetković, 2002a: p. 35) where it is written “The smallest particles that possess all properties of iron, copper and mercury and that can not be divided further are called atoms.” Similar definitions were reported by Papageorgiou & Sakka (2000). It is more than obvious that some adjustments need to be done in clarifying similar concepts present in the teaching of chemistry and physics.

Conclusion and Implications for Teaching

Several points need to be addressed concerning this study. The higher scores in the post-test showed that the intervention program was efficient, enabling students to gain more scientific explanations. The overall instruction was successful in facilitating understanding of particle theory concepts among students of different levels of study. In order for students to gain better knowledge and understanding, the researchers used lecture, discussions, written notes and clarifications and demonstrated several experiments. The improvement of the mean scores was

shown to be statistically significant for all sub-samples. Furthermore, the better results in the post-tests (for all samples) are in favor of the conclusion that indeed there is a noticeable improvement in the achievements of students for all test items (except for one in the sample of eighth-grade students).

With respect to the trends in understanding the particle theory concepts by students across the various levels of study, an increase of the *t*-values was noticed, although the second value in **Table 2** is opposite to this reasoning. Nevertheless, it was practically impossible to detect a strict regularity about the learning progress and the achievement of students since there was not a big difference in understanding of students of different age. Similar results are reported in the literature (Özmen, 2011).

One of the main points of this research was to detect misunderstandings and difficulties regarding the particle theory concepts, especially those related to the three levels of thinking (macroscopic, sub-microscopic and symbolic). Seven misconceptions represented by more than 20% were registered among students of all levels of study and three additional misconceptions were found in certain sub-samples. Many students claimed that the particles either decrease or increase their size when a substance is heated, their notions originating (erroneously) from the observations of the macroscopic properties of substances. Approximately 35% of the students fail to recognize the ionic nature of copper(II) sulfate and even 88% of them believe that the substance (butadiene) reacts with one or more entities (atoms or molecules of bromine). At this point, it must be emphatically stated that neither the *substances* are *molecules* nor *molecules* are *substances* and such statements should be explicitly given in the textbooks and repeated, over and over again, by the teachers in the classrooms. In this respect, it is of little comfort that even the Nobel Foundation reported that the Nobel Prize in Physiology or Medicine 1998 was awarded jointly to Robert F. Furchgott, Louis J. Ignarro and Ferid Murad “for their discoveries concerning nitric oxide as a signalling molecule in the cardiovascular system” (The Nobel Prize in Physiology or Medicine 1998), thus showing how widespread is the imprudent mixing of macroscopic (nitric oxide, a substance) and sub-microscopic (molecule, a particle) points of view.

We tried to get insight into ideas of the students about the particles and their connection to substances using a concept test and group discussions. The test items (which were developed by the authors) are provided in **Appendix 1** and can be used to repeat the research to a different sample and to compare the findings. Although generalization beyond the data of this sample can not be guaranteed, some considerations could be valuable. In this study, we found out that a large portion of students held the belief that the molecules have the properties of the bulk matter. The reasons for emergence of these misconceptions are mainly due to the failure to distinguish between macroscopic and microscopic properties (Ben-Zvi & Gai, 1994; Bucat, 2004; Chandrasegaran et al., 2007; Treagust et al., 2011). Furthermore, the data analysis from the tests and focus group interviews clearly showed that students had certain difficulties about: 1) recognizing symbolic representations (e.g. confusing symbols for atoms and formulae for molecules); 2) making distinction between ionic and covalent substances and their particles and 3) the ability to distinguish substances from molecules (i.e. differentiate concepts at macroscopic and microscopic level).

The low understanding about the particle theory concepts may originate from the unstable previous knowledge of students and emphasising the rote learning (Dhindsa & Treagust, 2009; Salame et al., 2011) without making connections between tangible macroscopic phenomena and changes at the molecular level. The abstract nature of many chemical terms (such as atoms, molecules, ions, electrons etc.) may also be a source of misconceptions. The fact that we are not able to see particles and their interconnection and interaction, compels us to apply a model which would help in acquiring understanding. As Coll & Treagust (2003) noted “*To understand and explain the macroscopic, we need to have a picture or image-a model-of what is going on at the microscopic level*”. Therefore, the necessity of using visualization techniques (models, animations or computer software) is obvious and it was mentioned as a required tool in teaching abstract concepts (José & Williamson, 2005; Milne, 1999). However, introducing models or images to students must be done with caution; otherwise it could be unproductive or even counterproductive. Eilks et al. (2012), with reference to their earlier studies, state that curriculum developers and textbook authors not always carefully incorporate important research evidence when preparing learning materials, as a result of which potentially misleading visualisations can be found in some German textbooks.

Particle theory concepts are an integral part of the eighth-grade secondary-school curriculum in Republic of Macedonia. At the very beginning of learning chemistry as a subject, students encounter the bulk properties (physical and chemical) of substances, their changes, classifications etc. Next, they learn about the structure of substances. Chemical symbols, formulae and equations come later. Nonetheless, the results showed that the sample of students have not developed an accurate understanding of these concepts. Furthermore, a remarkable consistency in reasoning was observed among students of different levels of study, thus confirming the fact that many students retain their misconceptions over the years.

Therefore, it is of utmost importance to make a clear differentiation between sub-microscopic entities and macroscopic phenomena in chemistry (Silberberg, 2006) and, consequently, their appropriate implementation in chemistry teaching. By all means, a special caution should be taken when teaching the youngest students in order to enable them to create proper mental images concerning the basic chemical concepts.

There are, at least, two main starting points useful in teaching chemistry: a) the “cognitive conflict” strategy that includes the use of diagnostic questions whose purpose is to stimulate students to talk about their ideas and utilizing the answers of the participating students to establish and organize teaching and b) carefully introducing the new material (ideas or concepts) visually, using pictures, animations and models of atoms and molecules and presenting new ideas consistently in other topics, thus forming an all-inclusive, integrated whole, instead of teaching different topics isolated.

Unfortunately, within the educational system in Macedonia many obstacles exist (including financial, experimental, personal prerequisites and, especially, the time allowed to the teachers) which would hamper the implementation of our deep conviction outlined above.

Our future studies will be aimed at other aspects of this (or a similar) research. An important issue will be testing the influence of gender on achievements of students. Preparing teaching materials to reduce erroneous notions (and help teacher to di-

agnose and address misconceptions before the instruction process) is deemed equally important.

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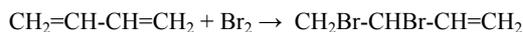
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Appendix 1: The Multiple-Choice Instrument

1) Which of the following statements regarding the bromination of butadiene represented by the equation



correctly describes what happens?

- butadiene reacts with two bromines.
 - butadiene reacts with one molecule of bromine.
 - one mole butadiene reacts with one mole bromine.
 - one gram butadiene reacts with one gram bromine.
- e) _____
- 2) Copper(II) sulfate from aqueous solution crystallizes:
- with five molecules of water.
 - as a solid substance composed of copper(II) sulfate molecules.
 - as a pentahydrate.
 - as an anhydrous salt.
- e) _____
- 3) In the process of ice melting, the volume of the system (mixture of ice and liquid water):
- decreases.
 - increases.
 - remains the same.
- 4) The reason for your answer to the third question is:
- ice particles are smaller than the water particles.
 - ice particles are bigger than the water particles.
 - particles change from solid to liquid ones.
 - the density of the system increases.
 - the density of the system decreases.
 - particles receive heat and enlarge.
 - the change in temperature changes the size of the particles.
- h) _____
- 5) What happens with the carbon, hydrogen and oxygen atoms, of which ethanol is composed, when it is ignited?
- they will ignite too and will burn just like the ethanol.
 - they will disappear.
 - they will become part of some other substance(s), different from ethanol.
- d) _____
- 6) What happens with the particles of a substance during heating that substance?
- they enlarge.
 - they shrink.
 - their size does not change.
- d) _____

Appendix 2: Interview Protocol

Phase 1 (Briefing phase, not recorded)

- Information about the purpose of the research and explanations about the procedure of the interviewing process.
- Ethical considerations (permission for audio-tape recordings, confidentiality of the obtained information etc.).

- Introductory questions, such as: “How do you picture atoms and molecules? What can you say about their appearance?”, “Name several substances and write down their symbolic representations”. “Are these substances composed of molecules?”

Phase 2 (Main phase, recorded)

- Discussion related to M1 and M2:
Write down one example of a chemical reaction. What do these symbolic representations stand for? What are the qualitative and quantitative information that can be drawn out?
- Discussion related to M3:
Write down an example of a crystalline hydrate. What does this symbolic representation stand for? What are the qualitative and quantitative information that can be drawn out? The discussion continues with students’ views of ionic and covalent substances, their distinction and their building particles.
- Discussion related to M4 and M5:
Have you ever put a plastic water-filled bottle in a deep-freeze? What happened? What happens if you put ice cubes in a glass of water? Why? Further discussions on the volume and density of ice compared to those of liquid water (the lakes freezing on the surface, the rock breaking due to freezing of water inside the gaps etc.).
- Discussion related to M6:
What happens with atoms of a certain substance upon burning? Is burning of alcohol different from the other types of burning?
- Discussion related to M5 and M7:
[Making models of water molecules]. Water evaporates at any temperature, but this process is more significant upon heating and boiling. Could you describe what happens with the water molecules during evaporation?
Water as a substance exists in three states: solid, liquid and gaseous. Explain what happens with the water molecules during a phase change. Do you think they are different in different phases? If you do, explain how. [An assignment was given to those students who claimed that molecules are different, to make new models of water molecules in different phases].
Do you think that temperature, pressure or some other external factor have an influence on atoms or molecules? If you do, explain how. Do you have further examples of this?

Gold has a characteristic golden color, copper is brick red and iodine is dark purple. Having this in mind, is it possible to draw a conclusion about the color of the atoms (or molecules) of which these substances consist?

As a conclusion: Do you think that the properties of the building particles are the same as those of the parent material?

Phase 3 (Debriefing phase, not recorded)

- Asking the participants whether they have anything else to add to the discussion or additional questions to pose.