JOURNAL OF BALTIC SCIENCE EDUCATION
ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

HISTORY OF CHEMISTRY AS A PART OF ASSESSMENT OF STUDENTS' UNDERSTANDING OF THE LAW OF CONSERVATION OF MASS

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Abstract. *The aim of this research was to explore students' ideas about chemical reactions and difficulties in understanding the law of conservation of mass in such reactions by using an approach that started from presentations of scientists' work associated with the law. The developed test items relied on: 1) the historical contents that illustrate the experimental work of three scientists (Lavoisier, Landolt and Lomonosov); 2) the description of school experiments and 3) real life situation. In this way, students would have an opportunity to show understanding of the law of conservation of mass in two contexts, one based on the stories from the history of chemistry and the other contemporary, based on school laboratory experiments and real life situation. Students of different ages were selected for the research: the seventh and the eighth grade of primary school (age 13–14), and the second year of grammar school (age 16). The research involved a total of 301 students. The results indicated that students' difficulties were mostly associated with the predictions and explanations of mass changes in open reaction systems in which a gas was a reactant than with the reactions in which a gas was a product.*

Keywords: *assessment in chemistry, grammar school, history of chemistry, experimental results, law of conservation of mass.*

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Introduction

The process of construction of scientific knowledge and the cognitive development of students are dependent upon the interaction of their cognitive structures and the structures of scientific knowledge organized into systems that are provided by the curricula. Classroom assessment, which is a vital part of the teaching process and thus inseparable from it, is considered to be a specific sociocultural context with deep impacts on the process of students' learning. The assessment techniques affect the way individuals perceive themselves and the decisions they make in order to stimulate their own progress in learning. Research results have indicated that the content, presentation and format of a test, and individual psychology influence the achievements of students (Danili & Reid, 2005). Students with high achievements when tested by one method may not be equally successful when tested in another way (Danili & Reid, 2006). When designing and planning assessment, it is important to think about different ways in which students' understanding could be reviewed and challenged.

In the research literature many terms refer to students' faulty views in science such as *preconceptions, pre-concepts, intuitive ideas or naïve beliefs, misconceptions, misunderstandings, intuitive theories, alternative conceptions,* etc. (e.g., Abimbola, 1988; Barke, Haziri & Yitbarek, 2009; Benson, Wittrock & Baur, 1993; Caramazza, McCloskey & Green, 1980; Chang, Lee & Yen, 2010; Clement, Brown & Zeitsman, 1989; Driver & Easley, 1978; Garnett, Garnett & Hackling, 1995; Gilbert & Watts, 1983; Nakhleh, 1992; Taber, 2009; Taber, 2015). Some authors emphasized the difference between the students' ideas developed without having any prior knowledge of the subject, termed *alternative*, *original* or *pre-concepts*, and those caused by inappropriate elements of teaching process, termed *school-made misconceptions* (Barke, Haziri & Yitbarek, 2009, p. 21). Misconceptions have been identified in many topics learnt in chemistry (Coll & Treagust, 2001; Dhindsa & Treagust, 2009; Nahum, Hofstein, Mamlok-Naaman & Bar-Dov, 2004; Nakhleh, 1992; Nakiboglu, 2003;

Park & Light, 2009; Stefani & Tsaparlis, 2009; Taber, 2009; Unal, Costu & Ayas, 2010). In the review of researches (Kind, 2004) students' misconceptions have been recognised in eleven conceptual areas of chemistry: states of matter; particle theory; changes of state; distinguishing between elements, compounds and mixtures; physical and chemical change; open and closed system chemical events; acids, bases and neutralisation; stoichiometry; chemical bonding; thermodynamics and chemical equilibrium. Many of the misconceptions relate to the abstract entities used in chemical explanations at the level of atoms and molecules (Taber, 2009). The research-diagnosed misconceptions could be very useful for the improvement of chemistry teaching, i.e. classroom activities and instructional materials (Al-Balushi, Ambusaidi, Al-Shuaili & Taylor, 2012; Ozmen, 2004).

The application of a wide range of teaching and evaluation strategies could bring the science contents and processes closer to a larger number of students. Many educators and researchers have advocated the presentation of interesting stories from the history of science as a valuable support for students to learn the contents of natural sciences and to form a picture about the science development (Table 1). They have stated that these stories could help in the clarification of various aspects of scientific research, in understanding the humane aspects of science and the role it plays in the development of different cultures (Folino, 2000; Paixao & Cachapuz, 2000). A positive effect can be reached by linking the discoveries in chemistry in the past with a wide range of products based on these discoveries commonly used nowadays (Stock, 2004). In a research of experts' views about using history and philosophy of science, Galilli & Hazan (2001a) found that some of them argued that presenting science as a story of conceptual revolutions could lead to students' conceptual change and to high effectiveness of instruction.

Table 1. A review of the literature on positive and negative impacts, or the absence of the influence of the application of history of science on the students' knowledge and attitudes toward science.

History of science in science education	Positive effects	Negative or no effects
Enables deeper understanding of scientific concepts in comparison with another context	Galili & Hazan, 2000; Lin, 1998; Seroglou, Panagiotis & Tselfes, 1998; Sneider & Ohadi, 1998.	Irwin, 2000; Kim & Irving, 2010.
Enables understanding of the nature of science	Galili & Hazan, 2001b; Faria, Pereira & Chagas, 2012; Irwin, 2000; Kalman, 2010; Kim & Irving, 2010; Solomon, Duveen & Scot, 1992; Solomon, Duveen & Scot, 1994.	Abd-El-Khalick & Lederman, 2000; Leach, Hind & Ryder, 2003.
Encourages students' learning based on errors in scientists' reasoning	Allchin, 2012; Dedes, 2005; Giunta, 2001; Kipnis, 2011.	-
Has potential to motivate students to learn science and develop positive attitudes about science	Dibattista & Morgese, 2013; Faria, Pereira & Chagas, 2012; Mamlok-Naaman, Ben-Zvi, Hofstein, Menis & Erduran, 2005.	-

Historical texts and experiments have been implemented in several approaches to science education (Allchin, Andersen & Nielsen, 2014), but their actual effect in chemistry teaching has been explored only a few times. How the contents from the history of chemistry shape students' further intellectual engagement in chemistry learning and whether they use the knowledge about the scientists' work in a new situation have not yet been the focus of research.

Research Focus

The aim of this research was to explore students' ideas about chemical reactions and difficulties in understanding the law of conservation of mass in such reactions by using an approach that started from presentations of scientists' work associated with mass conservation in chemical reactions. Accordingly, the specific research ques-

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

tion was: Could the stories about the discovery of the law of conservation of mass help the primary and grammar school students to understand this law in the context of contemporary school experiments or real life?

The law of conservation of mass was selected as an important basis for students' understanding of the quantitative aspects of the chemical changes of substances. This is an important starting point for students' understanding of the meaning and successful writing of chemical equations, as well as for conducting stoichiometric calculations according to them. However, the results of several studies have indicated that many students could neither predict nor explain mass changes in chemical reactions, nor successfully perform stoichiometric calculations (Ben-Zvi, Eylon & Silberstein, 1988; Hesse & Anderson, 1992; Mulford & Robinson, 2002; Ozmen & Ayas, 2003).

Methodology of Research

General Background

The conducted research is quantitative in nature (Cohen, Manion & Morrison, 2009). The test was constructed in order to obtain the answer to the research question, and students of different ages were tested. Testing in each group of students lasted one classroom period (45 minutes). The research was conducted with students from six primary schools and three grammar schools.

Sample

A total of 301 students attending the seventh and the eighth grade of primary schools (aged 13 and 14) and the second year of grammar schools (aged 16) in Serbia took part in the research (Table 2). The schools making up the sample were selected in such a way that the conditions in them, the state of the equipment that they possessed and the level of qualification of their teachers corresponded to the average conditions under which chemistry teaching in our country is conducted.

Table 2. The number of the students in the sample according to their educational level and school type.

Schools	Primary		Grammar
	7th grade	8th grade	2nd year
The No. of students	90	107	104

Primary education in Serbia is compulsory and lasts eight years (students ages 7 to 14). Chemistry starts being taught within separate subject in the seventh grade of primary school (students age 13). Secondary education in Serbia includes either four years of general education in grammar schools, which prepare students for tertiary level of education, or three or four years of vocational education.

According to the chemistry curricula for primary and grammar schools in Serbia, all students in the sample have already studied the law of conservation of mass before this research (the law of conservation of mass is elaborated for the first time in the seventh grade of primary school).

Throughout the research, the ethical guidelines for research within science education were followed. In order to obtain the consent from the schools, the research proposal was presented to the science committee in each school. The necessary permissions were obtained from the school science committees and the contracts which regulate the collaboration between the Faculty of Chemistry and each school were signed. The purpose of the testing was explained to the students before conducting the research. Participation of the students was voluntarily and the collected data were treated as confidential.

Development of the Instrument

Based on the results of descriptive content analysis of existing curricula materials and commonly known historical facts about the discovery of the law of conservation of mass (Brock, 2000; Grdenic, 2001; Partington, 1937) and the work of three scientists: the French scientist Antoine Laurent Lavoisier, the Russian Mikhail Vasilyevich

Lomonosov, and the German chemist (born in Switzerland) Hans Heinrich Landolt, the texts were composed and included in the test. The test also contained additional texts with descriptions and pictures of the setups of the experiments in the school laboratory. This allowed the formation of test items that rely on: 1) the historical contents that illustrate the experimental work of the scientists; 2) the description of experiments in a school laboratory and 3) situation from real life. In this way, students have the opportunity to show their understanding of the law of conservation of mass in two contexts, one based on the stories from the history of chemistry and the other contemporary, based on school laboratory experiments and real life situation.

The test contained 10 items with a total of 18 open and closed type requirements (Appendix 1), designed according to an analysis of the contents on the law of conservation of mass in currently used chemistry textbooks for primary and grammar schools. The testing did not involve conducting the experiments described in the test.

One step in this research was to define the indicators of students' understanding that would be monitored from the test results. The indicators and the requirements of the items in which they could appear are listed in Table 3.

Table 3. The indicators of the students' understanding and the items by which they are monitored.

Indicators	Description	The No. of the item
1 Predicting the results of the experiment	Based on the description of the experiments and pictures.	5.A); 6.A); 6.C); 7.A); 8.A); 8.B)
2 Formulating explanations	Based on the text concerning the experimental work of the scientist.	2, 3, 4, 9
	Based on the description of the experiments and pictures.	5.C); 6.B); 6.D); 8.C)
3 Formulating conclusions	Based on the text concerning the experimental work of the scientist.	1.
	Based on the description of the experiments and pictures.	5.B); 7.B)
4 Linking	Linking theoretical knowledge and situation from real life.	10.

To confirm the content validity, a group of experts comprising twelve chemistry teachers examined the test: five from primary schools and seven from grammar schools. The teachers also estimated whether students from all three groups of respondents during the regular chemistry classes had an opportunity to develop the necessary pre-knowledge for understanding the information presented textually or by images in the test, and according to that, whether it was possible to expect that students from each group could respond to the test requirements. Coding students' responses, *i.e.* determining if an answer was completely correct or partially correct was accomplished in cooperation with these teachers (Appendix 2).

Reliability was examined by the Cronbach's *a* coefficient which provides the correlation of each item with the sum of all the other items. The obtained value was 0.603 and indicates weak correlations among students' responses to the items (the Cronbach's *a* value of 0.70 is often considered as indicator of acceptable reliability). However, the views that the Cronbach's *a* value is an inappropriate indicator of reliability in the situation when students may hold a fragmented understanding of chemistry could be found in the literature (Adams & Wieman, 2011; Lu & Bi, 2016; Luxford & Bretz, 2014).

Data Analysis

The collected data were processed by using the statistical program for social science (SPSS). A one-way analysis of variance (ANOVA) was conducted in order to explore whether there were any differences among the groups' mean scores in the test. The *t* test was used to explore the statistical significance of the difference in the percentage of correct answers for each item between groups.

Results of Research

The characteristics of distribution of the overall results are presented in Table 4. The *skewness* and *kurtosis* values of the variables (Table 4) fall within the ranges (±1), therefore the data from each group is normally distributed.

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table 4. The characteristics of distribution of the results in all groups of participants (maximal score: 18).

Groups	N	Min	Max	Mean	SD	p	Skewness	Kurtosis
7th grade of primary school	90	2	16	8.3	3.0	46.1	0.197	-0.270
8th grade of primary school	107	2	15	8.2	2.6	45.6	0.027	0.040
2nd year of grammar school	104	4	17	9.2	3.1	51.1	0.273	-0.702

Analysis of variance (Table 5) found that there was a statistically significant difference between the achievements of three groups of students in the test ($F = 3.50$; $p < .05$). The Tukey test (Cohen, Manion & Morrison, 2009, pp. 547-550) found that the means for the seventh graders and the eighth graders were not statistically significantly different from each other, and that the means for the seventh graders and the grammar school students were not statistically significantly different from each other. The Tukey test also showed that the mean for the grammar school students was statistically significantly higher than the mean for the eighth graders at the .05 level.

Table 5. One-way ANOVA results for the test mean scores.

		SS	*df*	*MS*	*F*	*p*
Test	Between groups	58.75	2	29.38	3.50	.03*
	Within groups	2502.66	298	8.40		
	Total	2561.42	300			

** statistically significant at p < .05*

Table 6 presents the percentage of students in all groups who accurately fulfilled the items in the test, as well as the values of the *t*-test, which was used to explore the statistical significance of the difference in the percentage of correct answers between groups.

Table 6. The percentage of correct answers in the groups and the corresponding *t* values.

	The percentage of correct answers			t		
Items	7th Grade	8th Grade	2nd Year	$p_7 - p_8$	$p_7 - p_2$	$p_8 - p_2$
1.	61.1	58.9	62.5	0.31	–0.20	–0.54
2.	18.9	12.1	28.9	1.32	–1.61	–3.03**
3.	42.2	31.8	46.2	1.51	–0.56	–2.15*
4.	33.3	21.5	12.5	1.86	3.48**	1.74
5. A	34.4	31.8	56.7	0.39	–3.11**	–3.64**
5. B	86.7	82.2	61.6	0.86	3.95**	3.33**
5. C	5.6	3.7	14.4	0.64	–2.01*	–2.72**
6. A	50.0	48.6	50.0	0.20	0.00	–0.2
6. B	61.1	77.6	77.9	–2.52*	–2.55*	–0.05
6. C	73.3	67.3	76.9	0.92	0,75	–1.55
6. D	27.8	5.6	16.3	4.26**	1.94	–2.50*
7. A	70.0	63.6	79.8	0.95	–1.75	–2.61**
7. B	51.1	49.5	57.7	0.22	–0.92	–1.19
8. A	62.2	66.4	79.8	–0.61	–2.71**	–2.19*
8. B	63.3	68.2	76.9	–0.72	–2.07*	–1.41
8. C	28.9	30.8	36.5	–0.29	–1.12	–0.88

	The percentage of correct answers			t		
Items	7th Grade	8th Grade	2nd Year	$p_7 - p_8$	$p_7 - p_2$	$p_8 - p_2$
9.	48.9	69.2	50.9	–2.90**	–0.29	2.71**
10.	13.3	12.1	30.8	0.25	–2.90**	–3.32**

** The difference in the percentage of correct answers is statistically significant at the level of .05.*
*** The difference in the percentage of correct answers is statistically significant at the level of .01.*

The percentages of the correct answers in all groups of students according to the indicators in Table 3 are shown in the figures below (Figure 1 - in relation to *the prediction of the experimental results*, Figure 2 - in relation to *explanations*, and Figure 3 - in relation to *conclusions*).

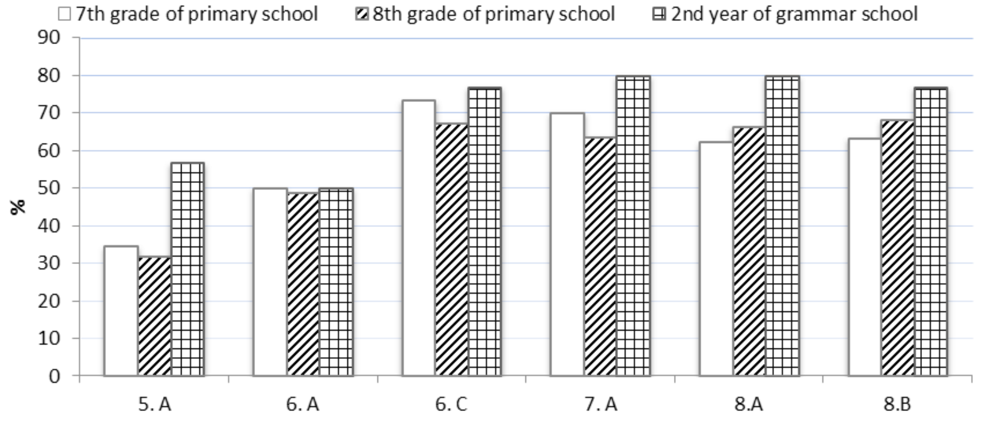

Figure 1: The percentage of correct predictions of the experimental results.

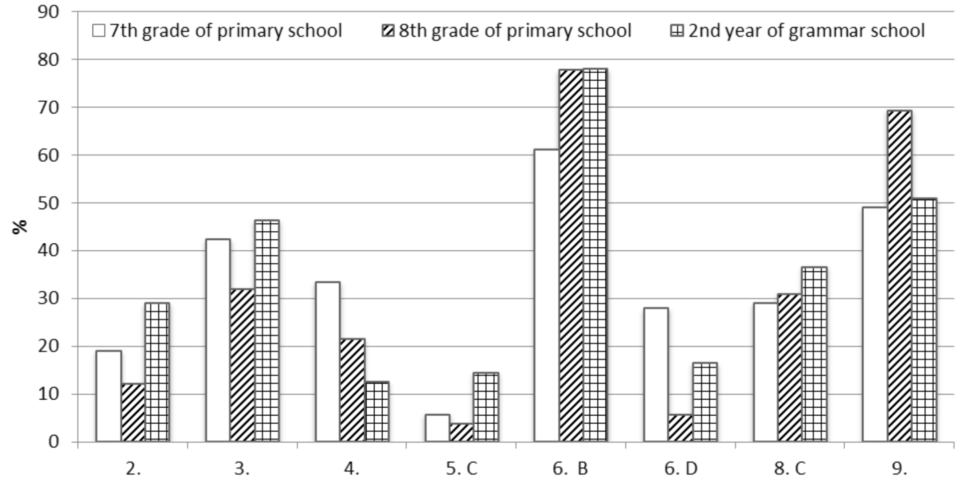

Figure 2: The percentage of exact explanations in the groups of the respondents.

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

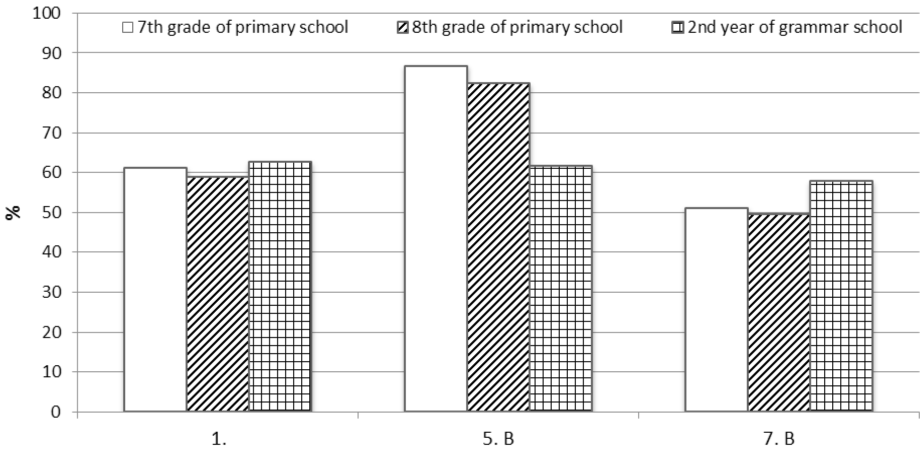

Figure 3: The percentage of correct conclusions.

The analyses of students' explanations based on the description of the experiments identified four levels of responses ranging from misconceptions to multiple factor influences. These levels represent a modified version of the construct map for the conceptual sophistication construct (Brown, Nagashima, Fu, Timms & Wilson, 2010). The students' answers labelled as misconceptions were divided into two categories: (i) productive misconception, which indicates the nature of the problem in reasoning and can serve as the basis for the further intervention in teaching practice and (ii) unproductive misconception - without clear information for the further intervention in teaching practice. Examples of students' explanations of the experiments at different levels for Item 5.C and Item 6.D are presented in Table 7, and Table 8, respectively. These items are chosen for presentation in the article because the students' answers on these items indicate their difficulties associated with the explanations of mass changes in open reaction systems in which a gas is a reactant or a product.

Table 7. Examples of students' explanations for item 5.C.

Response Level (Description)	Grade	Example Responses
Multiple factors Refers to the reaction of a nail with oxygen and the validity of the law of conservation of mass.	7th	'The mass of the rusted nail is greater than the mass of the nail before corrosion. Nikola would have proven the validity of the law of conservation of mass if he had measured the mass of the second reactant - oxygen.'
	8th	'The Lavoisier's law is valid. The mass of the reacted iron and oxygen (reactants) is equal to the mass of the completely rusted iron nail (product of the chemical reaction).'
	2nd	'The mass of the completely rusted nail is greater than the original nail mass, but it is equal to the mass of a clean nail and oxygen which reacted with the nail. The law confirms this.'
Singular factor Refers to the conditions under which the experiment was conducted.	7th	'The law is valid, because Lavoisier, unlike Nikola, conducted measurements in the sealed vessels and measured all the gasses inside.'
	8th	'The law is valid, because Nikola did not measure the mass of hermetically sealed vessel with the nail.'
	2nd	'Nikola did not conduct the experiment in a sealed container. The gaseous substances, which have a mass, were not measured.'
Reproduction	7th	'The total mass of the substances taking part in a chemical reaction remains the same before and after the reaction.'
	8th	
	2nd	

Response Level (Description)	Grade	Example Responses
Productive misconceptions	7th	'The nail changed its shape but not its mass after the chemical reaction had taken place.' 'The nail reacted with water and because of that the mass of the nail was changed.' 'The nail reacted with water and rust was formed. The mass of the nail remained the same.' 'The law is valid. If we measured the mass of the nail, the mass of rust and the mass of the rusted nail, we would notice that the sum of masses of the nail and rust is equal to the mass of the rusted nail.' 'After the rain, the nail is dissolved in rust and because of that the law is valid. '
	8th	'The mass of rust is added to the original nail mass.' 'Metal reacted with rain and a layer of rust was formed on the metal's surface, but the mass of the metal did not change.' 'The surface of the nail changed its physical property but not its mass.' 'We can apply the law of conservation of mass in this case. The nail reacts, it changes shape, but its mass remains the same.' 'The sum of the masses of the nail and rust is equal to the original nail mass.' 'Oxygen is released in the process of corrosion.'
	2nd	'According to the law of conservation of mass, the mass of the nail before and after the reaction with water remains the same.' 'The mass of the nail and the mass of water are equal to the mass of the rusted nail.' 'Firstly, the nail was shiny and smooth. A layer of rust was formed on the surface of the nail after the rain. Because of that, the nail has the greater mass than the nail before corrosion. If we removed rust, the nail would have the same mass as the shiny nail.' 'Although the nail has lost its lustre after the rain and the rust has been formed, the mass of the nail remains the same. The shape of the nail is changed.' 'Because, the iron nail reacted with water and oxides, the mass of which had not been measured.' 'The nail has changed its physical properties but the mass of the nail has remained the same.' 'The mass of the nail has probably decreased in the process of corrosion.'
Unproductive misconceptions	7th	'A new kind of substance is attached on the surface of the nail. I think it is some kind of lime.'
	8th	'The nail lost its lustre, which has no mass, and received the rust, which also has no mass, so the mass of the nail remained the same.'
	2nd	'The air makes iron passive.'

Table 8. Examples of students' explanations for Item 6.D.

Response Level (Description)	Grade	Example Responses
Multiple factors Refers to the results of both experiments.	7th	'Ana has not covered the burning candle with a jar and because of that the gaseous substances have escaped and the balance showed the smaller mass after burning. Marija has covered the burning candle with a jar so the gaseous substances have remained under the jar and can be measured.'
	8th	'If we retain the gases realised during a chemical reaction the total mass will remain the same. If we measure the mass of candle without measuring the mass of the released gases, the mass of candle after burning will be smaller.'
	2nd	'Marija's candle was covered with a jar, which prevents escape of the gas, so the total mass remained the same. Ana's candle was not covered and the gas escaped, so the measured mass after burning was smaller.'
Singular factor Refers to the results of only one experiment.	7th	'The total mass in Marija's experiment remained the same because all the gases were retained in the jar.'
	8th	'The total mass in Marija's experiment remained the same because the candle was burning in a closed system.'
	2nd	'The candle burnt in a closed jar and all released gases were retained in the jar, so the total mass remained the same.'

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Response Level (Description)	Grade	Example Responses
Reproduction	7th	'The total mass of the substances taking part in a chemical reaction remains the same before and after the reaction.'
	8th	
	2nd	
Productive misconceptions	7th	'The wax was melting while the candle was burning. Although the wax has changed its shape it still has the same mass.'
	8th	'The melted wax flowed to the cardboard in both experiments, so the weight of the candles did not decrease and the results of measurements of masses were identical.' 'During the combustion, the mass of the candle will decrease because of its melting.'
	2nd	'In Ana's experiment, the mass of the candle increased because the candle reacted with oxygen from the air which had not been measured by the balance. In Marija's experiment, the candle reacted with oxygen under the jar which had been measured by the balance.' 'Ana's candle only changed its state, while the mass of the candle remained the same. The mass of smoke was added to the mass of Marija's candle.' 'In Ana's experiment the mass of the candle is smaller because the mass of oxygen which reacts with the candle is not included.' 'The wax was melting and accumulating on the cardboard. No matter how much the candle melted, the mass of the candle remained the same. The candle only changed the shape.'
Unproductive misconceptions	7th	'Ana and Marija have added new reactants to the reactions, and because of that, we must take into account the mass of the subsequently added reactants.'
	8th	'The mass of the candle flame is small and negligible.'
	2nd	'The oxides are not formed in the experiment.'

Discussion

For the purpose of this research, the obtained results, i.e. what happened when students of different ages were asked to think about historical episodes and modern examples of a similar thought process, how they used the information from the texts about history of chemistry in the contemporary situations, are considered according to the indicators stated in Table 3.

Predicting the Results of the Experiment

Item 5.A requires the prediction of the mass of a rusted nail in relation to the mass it had before rust formation on the surface of the metal. It is a chemical reaction in an open system, which might produce a cognitive conflict in relation to the law of conservation of mass. For the primary school students it was the most difficult question of all associated with the prediction of the experimental results (Figure 1). Wrong answers in each group were mainly due to the expectation that the mass of the rusted nail would be the same as its mass before corrosion. This is consistent with the relevant literature indicating that kind of students' misconception (Driver, Guesne & Tiberghien, 1985, p. 145-169; Mulford & Robinson, 2002). Wrong answers indicate the tendency of students to strictly follow the formulation of the law of conservation of mass without reconsideration of the conditions in which the chemical reaction occurred. It was difficult for the primary school students to predict mass in an open system, especially when a gas was a reactant.

Item 6.A was also about a chemical reaction in an open system. The students were expected to predict the mass of a candle that had been burning for some time. The most frequent incorrect answers were predictions that the mass would stay the same.

Item 6.C was about predicting the mass of a jar with a burning candle, and with a lid on the jar (a closed system). The obtained results indicated that it was easier for the students to predict changes of mass in a closed system than in an open one.

Item 7.A gives a description of an experiment in which a jar with the solution of $Ca\ (OH)_2$ was placed on the balance. A smaller jar with a candle was placed into the jar containing the solution, the candle was lit and a bigger jar closed with a lid. The question was what mass values the balance would show after some time. The distracter *The balance will show a smaller mass because the candle melted down* dominated among the wrong answers of the primary-school students, while the distracter *The balance will show a larger value because a residue will form* was the most frequent answer of the grammar school students. Both answers indicate the students' misconception associated with expectation that the mass of the same amount of substances in the solid state is greater than in liquid or gaseous state (Mulford & Robinson, 2002; Ozmen & Ayas, 2003). However, the wrong answer of grammar school students indicates that they were thinking about a chemical change in the experiment, while in the same situation the primary school students who gave the wrong answer were focusing on the physical change (the change of state).

Items 8.A and 8.B contain a description of an experiment in which two glasses were placed on the balance. One glass was filled with a solution of sodium chloride, NaCl, and the other with a solution of silver nitrate, $AgNO_3$. The total mass of both glasses with the solutions was weighed. Then the solution from one glass was poured into the other, and the empty glass was also placed back on the balance. Item 8.A required students to state what indicated that a chemical reaction had taken place. Based on Figure 7 in the test, the expected answer was the formation of a residue. In Item 8.B, the students were expected to predict which mass value the balance would show after mixing the solutions. The wrong answers were mainly linked to the expectation that the balance would show higher values because of the formation of a precipitate, in accordance with the previous stated misconception.

Formulating Explanations

The overall achievement in all groups was low for the Item 2 related to the explanation of Lavoisier measurement of mass in the basement of the observatory where the air temperature was constant (Figure 2). Partially correct answers in all groups mainly included the limitation of the measuring instrument, but without the consideration of the conditions under which the measurements were performed (temperature, air humidity, *etc*.).

The explanation of the third item required an understanding of the problem related to the attestation of the validity of the law of conservation of mass in a closed system. Partially correct answers were obtained in all groups of students. A problem associated with the measuring of the mass of gases released in reactions was not recognized by the students.

Based on the given texts, the students were expected to provide an explanation to why Landolt sealed hermetically the H-shaped glass tube (Item 4). The students' explanations indicate that they accepted the facts about the experimental procedure but without deeper consideration of the reasons why Landolt had worked in such a way. According to the partially correct answers obtained in the research, most of the seventh-graders responded that Landolt had closed the vessel in order to prevent contact of the substances in the vessel with air. The eighth-graders had a similar idea, but also they answered "to enable the substances in the vessel to react". Moreover, some of them stated "to prevent leaking of substances from the vessel when it rotates". These responses indicate the tendency of the students to respond according to their own experience rather than to analyse for them a new situation (in this case, the description of Landolt's experiment).

The majority of students in all groups gave correct answer for Item 9 which was explicitly stated in the text about Lomonosov.

In the items related to experiments, the students in all groups were the least successful in trying to explain the mass of the rusted nail in relation to the mass before corrosion (Item 5.C). Students' answers (Table 7) showed that they had not identified oxygen as the second reactant in this reaction (they stated water or air). Among productive misconceptions, the majority said that in the process of corrosion the nail changed its shape but not its mass. Some students just quoted the law of conservation of mass in their answer (the level of reproduction).

About 15 % of students in each group provided the answer that the candle stopped burning because there was not enough air in the jar (Item 6.B). This answer indicates that these students did not make difference between air as the mixture of gases and oxygen as an element necessary for the combustion.

However, many incomplete explanations were given when the students were expected to compare and contrast the total mass of the reaction systems in both experiments: the burning candle in the open and closed system (Item 6.D). The students' answers for Item 6.D were analysed and ranged on four levels (Table 8). The answers at the singular level are related to the explanations provided only by Ana's experiment or only by Marija's experiment. The level of reproduction is comprised of the answers which quoted the law of conservation of mass. The productive misconceptions in all groups of students indicate that they did not perceive combustion as a chemical reaction. They explained that the wax was melting while the candle was burning but the mass of the candle remained the same or decreased. This kind of answer is associated with the previously mentioned misconceptions from literature about the greater mass of substances in solid state than in liquid state. The lack of comparison and contrasting of the results of

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two experimental settings indicates the students' tendency to be focused on one situation rather than to consider the relation open-closed reaction system.

Item 8.C required an explanation of what mass the balance would show after mixing the solutions of sodium chloride and silver nitrate. The wrong answers were mainly linked to the expectation that the balance would show higher values because of residue formation. As was already mentioned, the students' assumption that the total mass increases in a precipitation reaction is a known misconception associated with the expectation that solids have a greater mass than liquids (Ozmen & Ayas, 2003).

Formulating Conclusions

The comparison of the percentages of correct conclusions for the Item 5.B (Figure 3) and explanations for the Item 5.C (Figure 2) indicates the students' tendency in all groups to produce a "desirable" answer within the framework of the previously acquired knowledge about the law of conservation of mass without reconsideration of the already stated prediction of the experimental result (5.A; Figure 1). The expressiveness of this tendency was the lowest in the group of grammar school students.

The majority of students from each group correctly cited the formulation of the law of conservation of mass from the text about Lavoisier's work (Item 1). According to the students' answers, some of them still thought that the substance (a reactant) would stay chemically unchanged after the chemical reaction. Among them, some expressed this in the following way: *The mass of a substance does not change in the chemical reaction.* Some primary school students were not able to distinguish between mass and volume: *In spite of the changes in the shape of substances in the chemical reactions, the volume of substances remains the same.* Also, some students did not understand that the law of conservation of mass is valid for all chemical reactions. They thought that the law is valid only for the reactions in a closed system.

The lower results related to conclusions in all groups were achieved for the requirement 7.B, which comprises a description of the most complex experimental set up in which two chemical reactions occur. In the students' answers we found the same problems in understanding that we have already elaborated in previous discussion.

Linking

Item 10 should examine students' ability to link knowledge about the law of conservation of mass with chemical changes from a real life. A forest fire was given as an example. The problem of applying the knowledge of the law of conservation of mass to a real life situation was evident in all groups of students.

Conclusions

The achievements in all groups were low, but generally, the grammar school students showed better achievements than the primary school students. The mean for the grammar school students was statistically significantly higher than the mean of the eighth graders at the .05 level. The means for the grammar school students and the seventh graders were not statistically significantly different from each other. In addition, the means for the seventh graders and the eighth graders were not statistically significantly different from each other.

The results of this research showed that the texts about scientists' work may provide useful information for some students and not for others, perhaps those who have already developed some misconceptions associated with the structure of substances and chemical changes. Actually, the research results indicate that some students' misconceptions remain in all groups in spite of their insight into the scientists' work.

The obtained results indicated the students' difficulties related to predictions and explanations of mass changes in open reaction systems. These difficulties were mostly associated with the reactions in which a gas was a reactant and, consequently, the total mass of the system increased than with the reactions in which a gas was a product and total mass of the system decreased. The known misconception associated with the expectation that solids have a greater mass than liquids was also confirmed by the results of this research. When students were faced with the situation that included the same chemical reaction in open and closed systems and the requirement was to compare and contrast the results of the two experiments, they were not able to operate with the relation open–closed systems. The root of these difficulties may have been problems with students' understanding of the atomic model and its use in the explanation of macroscopic visible changes of substances during chemical reactions, as well as the understanding of laws according to which reactions occur.

From the achievements of the students, it is evident that they tend to accept information as given in the text without further consideration of the implications. From some students' answers, it was clear that they tried to adapt their answers to the formulation of the law of conservation of mass.

The obtained results indicate that the students try to fit, or "cover" explanations of evident phenomena and processes, which could be reached through common sense, with ready formulations without analytical or critical thinking. The fact is that they adapt their learning to the usual ways the achievements were assessed, which inevitably leads to inability to solve the problems set in different contexts from the one they were used to.

Limitations

Further validation may be needed in order to further determine the cause of the low Cronbach's *α* value. The reactions of the students indicated that this way of testing was a complete novelty to them and the limitations of this research are associated with the motivation of students to engage in this kind of work. In addition, we can assume that some students found it difficult to understand the historical stories and to use them to formulate their answers to the items in the test.

Acknowledgements

This research is the result of the work on the project "The Theory and Practice of Science in Society: Multidisciplinary, Educational and Intergenerational Perspectives", No. 179048, the realization of which is financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

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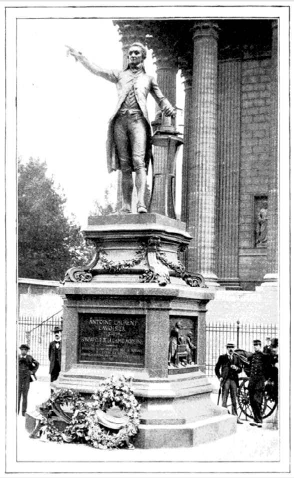
Appendix 1: The test

Antoine-Laurent Lavoisier (1743–1794)



Lavoisier was a French chemist and is widely considered as the founder of modern chemistry. He introduced quantitative measurement to the laboratory. A precise balance was his main instrument. Many of the Lavoisier's experiments were conducted in sealed glass containers from which matter could not escape or enter. He used accurate balances that could measure very small changes in mass during his experiments and carefully weighed the reactants and products of a chemical reaction. Lavoisier conducted the process of mass measurement in the basement of an observatory where the air temperature was constant.
In 1774 Lavoisier performed the following experiment: he warmed a tin in a sealed vessel containing air. He noticed the formation of a substance on the metal surface, marked at that time calx. Today we know that this was a layer of oxide. Lavoisier measured the vessel together with the metal, metal oxide and the rest of the air. He discovered that new substances were formed but that the container and its contents had the same mass as before heating. When he measured the mass of the new solid substances, he discovered that they were heavier than the original tin he had heated. In this way, he determined that it must have gained mass from the air. In experiments with phosphorus and sulphur, both of which burned readily, Lavoisier showed that they gained mass by combining with air. Based on these experiments, Lavoisier concluded that air contained several gases, one of which reacted with the elements in the experiments.
His findings implied that the total mass of the substances taking part in a chemical reaction remains the same before and after the reaction. Lavoisier established the law of conservation of mass, and chemistry became an exact science, one based on careful measurement.

1. Imagine you are Antoine Lavoisier and you conducted the experiments mentioned in the text. Based on the experimental results suggest the formulation of the law of conservation of mass.
2. Why is it important to perform measurements of mass on the same balance and under the same conditions?

Hans Heinrich Landolt (1831–1910)

Lavoisier's contemporaries had difficulties in proving the law of conservation of mass. The main problem was associated with the detection and measurement of all the reactants or products. It was particularly difficult to detect and measure the mass of gaseous reactants or products.
Landolt was a German chemist. He was born in Zurich in Switzerland. He experimentally verified the law of conservation of mass almost 100 years after its discovery by using an H-shaped glass tube (Figure 1). He filled silver nitrate into limb A and hydrochloric acid into limb B. The tube was hermetically sealed and weighed before the chemical reaction. The reactants were mixed by inverting and shaking the tube. A white precipitate of silver chloride was formed. The tube was weighed again. Landolt observed that total mass had remained practically constant after the reaction.

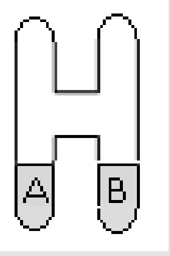


Fig. 1

3. What was the problem in experimentally proving the law of conservation of mass?
4. Why did Landolt use a hermetically sealed H-shaped glass tube in his experiment for the verification of the law of conservation of mass?

Five primary school students, Nikola, Ana, Marija, Jovan and Katarina had read the text on Lavoisier's work and his discovery of the law of conservation of mass. They wanted to experimentally verify the validity of the law.

Nikola wanted to experiment with a new nail. He measured the mass of the nail and recorded it. Then Nikola left the nail outside for a few rainy days. When he took the nail again, he noticed that the nail's surface was covered with a layer of rust. The student measured the mass of the rusty nail on the same balance.

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ISSN 2538–7138 /Online/

5.A. Circle the letter in front of the correct answer. The mass of the rusted nail in relation to the mass it had before rust formation on the surface of the metal was:

a) larger b) smaller c) the same

B. Circle the letter in front of the correct answer. Does the student's experiment confirm the Lavoisier's law of conservation of mass after more than 200 years from its discovery?

a) Yes, it does. b) No, it does not.

C. Explain the answer.

Ana first measured the mass of a candle (Figure 2) and recorded it. Then she lit the candle and left it to burn for a while (Figure 3). Subsequently, Ana extinguished the candle and measured its mass again (Figure 4).

Fig. 2


Fig. 3


Fig. 4

6. A. Circle the letter in front of the correct answer. What mass value will the balance show in Figure 4 in comparison with the mass in Figure 2?

a) Larger b) Smaller c) The same

The setting of Marija's experiment is shown in Figure 5 and Figure 6. She measured the mass of the burning candle covered with a jar and the mass of the candle when it extinguished.


Fig. 5


Fig. 6

B. Why did the candle extinguish under the jar?

C. Circle the letter in front of the correct answer. What mass value will the balance show in Figure 6 in comparison with the mass in Figure 5?

a) Larger b) Smaller c) The same

D. Explain the results of Ana's and Marija's experiments.

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Jovan placed a jar with a solution of Ca (OH)2 on the balance. A smaller jar with a candle was placed in the jar containing the solution (the top of smaller jar was over the level of solution of Ca (OH)2 in a bigger jar). The candle was lit and a bigger jar closed with a lid.

7. A. Circle the letter in front of the correct answer. What mass value will the balance show after some time?
   a) The balance will show a smaller mass because the candle diminished due to chemical change.
   b) The balance will show a smaller mass because the candle melted down.
   c) The balance will show a larger value because a residue will form.
   d) The balance will show the same value as at the beginning of the experiment.

B. What could Jovan conclude on the validity of the law of conservation of mass based on the presented experiment?

The setting of Katarina's experiment is presented in Figure 7.

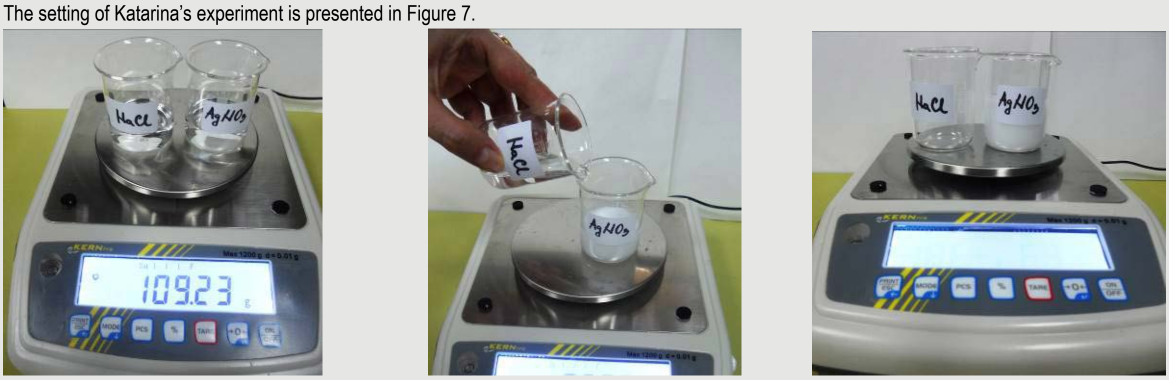

Fig. 7

8. A. What is the evidence that a chemical reaction occurred?

B. Circle the letter in front of the correct answer. The mass of the products of this reaction in comparison with the mass of the reactants is:
   a) larger   b) smaller   c) the same

C. Explain the answer.

Mikhail Vasilyevich Lomonosov (1711–1765)

Lomonosov was a Russian poet, grammarian and scientist. He hypothesized on the structure of matter, on the nature of combustion, and on heat. Lomonosov placed great emphasis on quantitative measurements in his work and had the idea about the conservation of mass in chemical reactions.

The idea of conservation of mass he expressed in the following way: "All changes in nature are such that inasmuch is taken from one object insomuch is added to another. So, if the amount of matter decreases in one place, it increases elsewhere."

The law of conservation of mass implies that matter can neither be created nor destroyed, so the number and type of atoms must be the same before and after the chemical reaction.

9. What is the main point from Lomonosov's formulation of the law of conservation of mass?

10. Forest fire is a huge environmental problem. The mass of ash after forest fire is less than the mass of wood before. Is the law of conservation of mass valid in this situation? Explain your answer.

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ISSN 2538–7138 /Online/

Appendix 2

The principles of coding the open-ended items in the test

Item	**Item was coded correct if the student:**
1	Stated that the total mass of substances is the same before and after the chemical reaction.
2	Explained the importance of performing measurements of the mass on the same balance, and under the same conditions. A completely correct answer includes both the importance of the same balance and the same conditions for obtaining the accurate and precise results of the measurements of mass. If the student included only one of these in his/her answer, the answer was coded as partially correct.
3	Explained the problems the scientists had in proving the law of conservation of mass related to the inability to detect and measure the gaseous reactants or products in chemical reactions.
4	Explained that the shape of hermetically sealed glass tube enables the measurements of the total mass of separated reactants in the limbs and the total mass of products of chemical reaction after mixing the substances.
5.C	Explained correctly the answers chosen for Items 5.A and 5.B. The correct explanation refers to the reaction of the nail with oxygen from the air and the nail mass increasing.
6.B	Explained the candle burning out under the jar. The correct explanation refers to the decrease in the concentration of oxygen and the increase in the concentration of carbon dioxide under the jar during combustion, which caused the candle to burn out.
6.D	Provided a full explanation of the results of Ana's and Marija's experiments. The full explanation reveals a distinction between Ana's and Marija's results of the measurement of mass of the burning candle in an open and closed system.
7.B	Made a correct conclusion about the validity of the law of conservation of mass based on the result of Jovan's experiment conducted in a closed system.
8.A	Pointed to the formation of the residue as evidence that the chemical reaction had taken place.
8.C	Explained the correctly chosen answer to Item 8.B. The correct explanation refers to the same total mass of two solutions at the beginning of the experiment and the total mass of mixture with the residue after mixing the solutions.
9	Explained that the law of conservation of mass implies that matter can neither be created nor destroyed.
10	Explained that the mass of wood and oxygen before the forest fire is equal to the sum of masses of ash and released gases during combustion.

Received: *July 15, 2017* Accepted: *September 28, 2017*

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