JOURNAL OF BALTIC SCIENCE EDUCATION

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

IDENTIFICATION OF THE UNDERSTANDING OF THE STATES OF MATTER OF WATER AND AIR AMONG SLOVENIAN STUDENTS AGED 12, 14 AND 16 YEARS THROUGH SOLVING AUTHENTIC TASKS

Miha Slapničar,
Iztok Devetak,
Saša A. Glažar,
Jerneja Pavlin

Abstract. *The aim of the research was to identify how Slovenian primary and secondary school students of various age groups explain the particulate nature of the states of matter of water and air. The qualitative research included five 12, 14, and 16 year old students. A semi-structured interview including four computer-displayed tasks was used for the data collection. The research results show that all of the students correctly identified the states of matter of water at the particulate level, but not of air. It was found that the students had difficulty justifying their selection. The study confirmed the existence of: (a) misunderstanding regarding the interpretation of the particulate nature of matter, (b) a failure to distinguish between particle and matter, and (c) the inadequate description of submicroscopic level of matter with macroscopic level concept. The survey results provide an insight into the mindset of students and serve as a starting point for teachers' lesson planning.*
Keywords: *authentic tasks, macroscopic level, misunderstanding of pressure, states of matter, submicroscopic level.*

Miha Slapničar, Iztok Devetak, Saša A. Glažar, Jerneja Pavlin
University of Ljubljana, Slovenia

Introduction

The learning content of science subjects is perceived as abstract and difficult to understand and learn. One of the challenges of modern science education concerns learning to understand science concepts, phenomena, and processes, as well as their application in solving authentic tasks (Wu, Krajcik & Soloway, 2001). The complexity of teaching and learning science, especially chemistry concepts, can be attributed to the representation of concepts at three levels: the macroscopic, the submicroscopic, and the symbolic. Science concepts can be represented by experiments or by observation of phenomena and processes – the macroscopic level. The interpretation of observations of the interaction between particulate matter is used to explain the observations with reference to theories based on the level of particulate matter – the submicroscopic level. This level can be illustrated with the agreed symbols – the symbolic level. Symbols that facilitate the interpretation of the actual state of natural phenomena and processes are usually chemical symbols, formulas and equations, mathematical equations, and various schematic and graphical presentations (Johnstone, 1982; Devetak, 2012; Taber, 2013). Students often have difficulty distinguishing between the description of a macro phenomenon and its explanation at the submicroscopic level, which is the basis of understanding science concepts prior to their symbolic representation (Devetak, 2012). When a student is capable of simultaneous integrative understanding of all three levels of representation concepts, s/he is able to successfully solve science tasks (Taber, 2013; Herga, Glažar & Dinevski, 2015).

The first person to systematically indicate the importance of the submicroscopic level of the chemical concept for a better understanding of natural phenomena was Johnstone (1982), who linked the importance of the interdependence of all the three levels with the triangle of the triple nature of the chemical concept (Figure 1, left). His model has been constantly upgraded by adding elements that focus on new knowledge and experience in the field of learning science concepts, including chemistry concepts. An example of this is the model of the interdependence of the three levels of science concepts. It includes all the elements in Johnstone's original model as well as connections between the different levels, which, using visualization techniques, allow for the formation of an appropriate mental model of the science concept (Devetak, 2005) (Figure 1, right). This is an individual's mental representation, which develops during the cognitive activity of the learner in his/her interaction with the object. If an individual has an improperly formed mental model, misinterpretations can arise that hinder his/her success in solving science tasks (Harrison & Treagust, 2000). The creation of a suitable functional mental model, which the student uses when acquiring new knowledge, enables the acquisition of knowledge through understanding (Moreno & Mayer, 2000). The student's understanding of science deepens as s/he progresses vertically in education (Chittleborough, 2014).

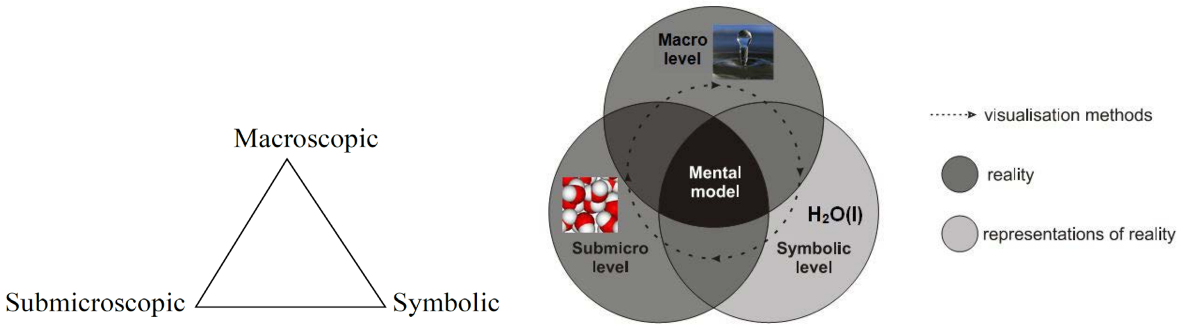


Figure 1: The triangular model of the triple nature of the chemical concept (Johnstone, 1982) (left), and a model of the interdependence of the three levels of science concepts (right) (Devetak, 2011).

Research confirms that students often develop an erroneous understanding of science concepts at the submicroscopic level (Devetak, Vogrinc & Glažar, 2009; Devetak, Drofenik Lorber, Juriševič & Glažar, 2009), including the states of matter (Bunce & Gabel 2002; Chiu, Chiu & Ho, 2002; Mulford & Robinson, 2002; Vermaat, Terlouw & Dijkstra, 2003; Kind, 2004). It was shown that students frequently attribute macroscopic properties to particulate matter, thus revealing an erroneous integration of the macroscopic and submicroscopic levels of particulate matter representations (Harrison & Treagust, 2000; Nicoll, 2001; Chiu et al., 2002). The results of research conducted by Pereira & Pestana (1991) showed that 13-year-old students perceived the states of water as macro phenomena, as they drew glasses for the liquid state of water, in which they marked the water surface; they drew an ice cube for the solid state of water, and they drew clouds for the gaseous state of water. It was established that the proportion of tested students who used macro representations to represent the state of water became smaller with advanced age. It was reported that 39 percent of 13- and 14-year-old students indicated an increase in particle size starting from the solid state, through the liquid state, to the gaseous state of matter. Researchers report the opinions of students that particles reduce in size when matter is cooled. Students also believe that, on warming or cooling matter, the particles of which the matter is composed are also heated or cooled (Harrison & Treagust, 2000; Mumba, Chabalengula & Banda, 2014). In one study (Toth & Kiss, 2006), students aged 13–17 years were asked to identify solid, gaseous and liquid matter in particulate presentations of matter. The respondents were most successful in identifying the distribution of particles in the solid state of matter, with 71 percent of the students providing the correct answer. The least success (58 percent of the students) was evident in choosing the correct representation of the distribution of particles in the liquid state.

Research results (Özmen, 2013) show that traditional learning strategies (frontal learning and working with textbook material) do not contribute to students developing an appropriate understanding of the concepts of *matter,* the *states of matter*, and the *particulate nature of matter*. In such learning strategies, dots or circles representing atoms, ions or molecules (Bunce & Gabel, 2002) are used to represent particles at the submicroscopic level. It is important that the representation of the distribution of the particulate matter is presented appropriately; otherwise, misunderstandings may be caused or deepened. Such misunderstandings are also associated with the weak prior knowledge of learners (Devetak, 2012). Many researchers have found that animations of submicroscopic representations of concepts contribute to a better understanding of the particulate nature of matter (Stern, Barnea

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

& Shaull, 2008; Limniou, Papadopoulos & Whitehead, 2009; Gregorius, Santosb, Danob & Gutierrezb, 2010; Falvo, Urban & Suits, 2011; Olakanmi, 2015).

The creation of mental models of a science concept at the submicroscopic level poses a significant problem for students, and animation is a more appropriate option for encouraging understanding of a process (Rodrigues, Smith & Ainley, 2001; Yang, Andre & Greenbow, 2003). The use of information technology seems to be important for giving students a better understanding of science learning content, as this approach is appealing to students, as well as to teachers; information technology is a motivational tool and enables higher quality science teaching (Vrtačnik et al., 2000; Yang et al., 2003; Olakanmi, 2015; Sarabando, Cravino & Soares, 2016).

Research Problem and Research Focus

The aims of the present research are: (a) to ascertain how and in what way (which level of the representation of a science concept) students of different ages answer questions in authentic tasks related to the states of water and air, (b) to identify what misconceptions students exhibit in dealing with authentic tasks that address the states of water and air, as well as the properties of gases, and (c) to formulate guidelines for the application of the obtained results for educational purposes. The study included four authentic tasks related to the physical states of water and air, and to the properties of gases. The Slovenian school system provides for the systematic addressing of learning content that includes the states of matter in the curriculum for science and technology (Balon, Gostinčar Blagotinšek, Papotnik, Skribe Dimec & Vodopivec, 2011) in the 5th grade (10 years of age). Students first encounter submicroscopic representations of the states of matter in the 6th grade of elementary school (11 years of age) (Skvarč et al., 2011), when they also learn more specifically about material flow, i.e., air flow. A detailed description of air and its properties is addressed in the 5th grade (10 years of age) and the 7th grade (12 years of age) of elementary school (Balon et al., 2011; Skvarč et al., 2011). In the 8th grade of elementary school (13 years of age), students upgrade their knowledge of the states of matter in chemistry, focusing on the arrangement and movement of particles (Bačnik et al., 2011). Learning content regarding the states of matter is repeated in physics in the 8th grade of elementary school (Verovnik et al., 2011). Elementary school knowledge is upgraded in high school education, where students once again focus on the states of matter, with an emphasis on submicroscopic representations of matter; this is covered by the learning objectives of chemistry in the first year of high school (15 years of age), and of physics in the second year (16 years of age) (Bačnik et al., 2009; Planinšič, Belina, Kukman & Cvahte, 2009). The interdependencies between the pressure, volume, and temperature of a gas may be presented to students (optional curriculum content) in physics in the 8th grade of elementary school, but is always addressed when dealing with gases in the first and second year of high school (Bačnik et al., 2009; Planinšič et al., 2009; Verovnik et al., 2011).

The aim of the present research is to identify the understanding of the states of water and air at the macroscopic and submicroscopic levels among students aged 12, 14 and 16. Two research questions were set:

RQ1: What are the misconceptions in students of various age groups in solving authentic tasks that include animations at the macroscopic and submicroscopic levels of the physical states of water and air?

RQ2: At what level of the representation of science concepts (macroscopic/submicroscopic) do students argument their selection of the appropriate animation with a submicroscopic representation of particles of water and air?

Research Methodology

A qualitative survey was used in the research. The data was gathered through a semi-structured interview with the aim to identify the understanding of the states of matter of water and air among Slovenian students aged 12, 14 and 16 years through solving authentic tasks. The semi-structured interviews were conducted with the research participants in May and September 2016 at the Faculty of Education, University of Ljubljana.

Research Sample

The non-random sample included 15 participants: 5 12-year-old students (3 girls and 2 boys), 5 14-year-old students (3 girls and 2 boys), and 5 16-year-old students (2 girls and 3 boys). To ensure anonymity, each student was assigned a code consisting of a serial number and the age of the student. The sampling method was purposive: the students were selected based on their previously expressed interest in science, their average achievements in science (their minimum grade was 3, whereby the grade 5 represents excellent knowledge), and their communication skills. The students were selected from a mixed urban population.

Instrument and Procedures

Similar studies on this topic commonly use questionnaires of the paper-pencil type, which do not provide an in-depth insight into the issue (Kind, 2004; Rahayu & Kita, 2009). In the present research, a semi-structured interview was used as a measuring instrument, which allows for closed and open-ended questions, as well as providing an opportunity to encourage the interviewee to answer the questions: if the given answer is not understandable, sub-questions can be posed (Vogrinc, 2008). The students were set four authentic computer-displayed tasks, of which three were dedicated to the understanding of the states of water, while the fourth concerned the properties of compressed air. The students responded to the questions of the authentic tasks, and the researcher posed sub-questions in the case of incomplete or incomprehensible answers.

The authentic tasks were created by three higher education teachers of chemistry and physics education. Prior to being used for research purposes, the tasks were evaluated by six teachers: four elementary school teachers (two-subject teachers: chemistry/physics/biology) and two secondary school teachers (chemistry teachers). The tasks were evaluated by the teachers at the Faculty of Education, University in Ljubljana, in November 2015. The teachers simultaneously commented on each displayed task; their comments were audio recorded, and the data obtained were later transcribed. Within the scope of evaluating the authentic tasks with a survey questionnaire of the paper-pencil type (on a five-point Likert-type-scale), the following items were also evaluated in addition to the substantive adequacy of the tasks: (1) the comprehensibility of the instructions and questions in each task, (2) the difficulty of each task, (3) whether the tasks were interesting, and (4) whether the tasks distinguished between students with better knowledge of science and those with poorer knowledge. Based on the opinions of the teacher practitioners, the tasks were meaningfully corrected, thus ensuring additional validity, objectivity, and reliability.

The authentic tasks cover two levels of representations: the macroscopic level and the submicroscopic level. The symbolic level is intentionally omitted, as 12- and 14-year-olds in the Slovenian education system are not yet familiar with the symbolic level of the states of matter (e.g., kinetic theory equations). The authentic tasks contain a text presentation (socio-scientific context), visualizations as animations at the submicroscopic level, and questions to be answered by the students. Each authentic task was presented by two or three sequentially displayed screen images, with relevant questions being asked each time. The response was followed by the next screen image. The screen image was usually divided into: (1) text related to the task; (2) photos of the states at the macroscopic level; (3) three animated representations of particulate matter, and (4) questions prompting the students to solve of the task.

The formulation of the questions related to the authentic tasks relied on the terminology used in Slovenian textbooks for science subjects, especially for chemistry (Vrtačnik, Wissiak Grm, Glažar & Godec, 2015; Devetak & Perdih, 2012). It should be noted that *water substance* has different names (ice/liquid water/steam) in different states of matter (solid/liquid/gas). The answer to the question at the submicroscopic level "What does the substance in the photo consist of?" is specifically *a water molecule*. The animation shows the submicroscopic level of the substance; thus, the argumentation of the selection of the correct animation requires an answer at the submicroscopic level.

Consent was obtained for the research participants from school boards, teachers, and parents, in accordance with the judgment of the ethics committee of the Faculty of Education, University of Ljubljana. In May and September 2016, semi-structured interviews were conducted with the research participants at the Faculty of Education, University of Ljubljana. The participating students read the authentic tasks from a computer screen, answered substantive questions, and evaluated the difficulty of the individual tasks. The individual 20-minute interviews were audio recorded and transcribed.

Data Analysis

The transcribed data were qualitatively processed according to the code of the students' answers. The responses were coded with regard to a previously prepared model answer, based on the content of current textbooks for primary and secondary schools approved by the Council of Experts of the Republic of Slovenia for General Education. Research was based on the interpretative paradigm, emphasizing the understanding of the interpretation of the particulate nature of water and air, and of the simultaneous integration of the macroscopic and submicroscopic particulate levels of water and air.

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

Results of Research

The results are presented according to the four authentic tasks. The questions in the first three tasks are similar. Each task is first briefly described, followed by a presentation of the students' answers. In the student's justification of his/her selection of the correct animation, at least two reasons had to be stated; only in this case was the answer considered to be fully correct. However, answers that only stated one reason and/or that were substantially incomplete were still acceptable, as were answers referring to a comparison of all three animations.

The first authentic task (Figure 2) was related to the recognition of the solid state of water. The students were asked to identify ice in the displayed photo and, from three animations offered, to select the appropriate distribution of water molecules in the solid state at the particulate level. They also had to justify their selection.

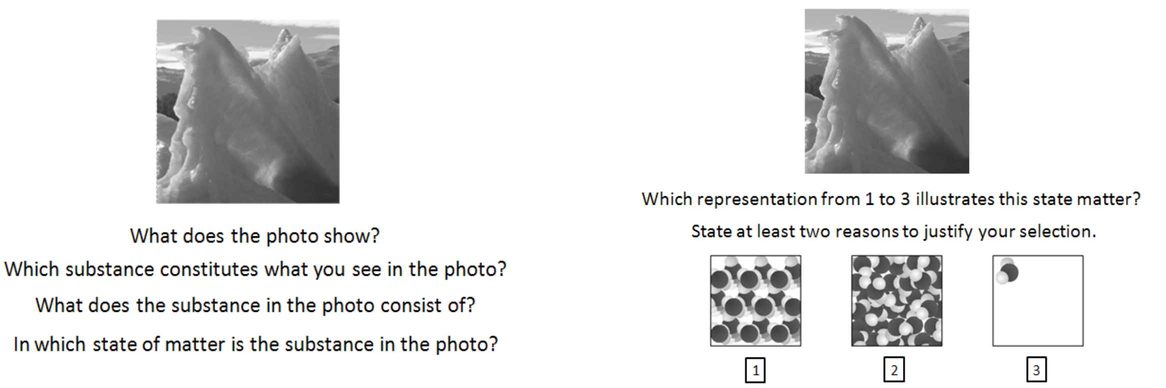


Figure 2: Screen images of the first authentic task.

(Image of iceberg from *hdwpics.com*).

The students' short answers to the questions in the first authentic task are presented in Table 1. All of the students recognized an iceberg/a glacier/a piece of ice/ice (Question 1a) in the photo. Question 1b required the students to name the substance of which ice is formed. Three students failed to provide the expected response: that ice is formed of water. Student 1/14 believed that ice was formed of hydrogen and carbon, whereas students 3/14 and 3/16 stated that ice was formed of ice.

Question 1c verified whether the students knew that water is made up of water molecules; the answer that water is made up of atoms was considered wrong, as the water molecule is the elementary particle of this substance, being composed of two hydrogen atoms and one oxygen atom. Instead of answering the question at the submicroscopic level as anticipated, the students answered it at the macroscopic level, with misunderstandings being identified in students of all age groups. None of the 12-year-olds responded correctly to Question 1c, while students 1/12 and 5/12 claimed that water was composed of water. Student 2/12 stated that water was made up of particles such as oxygen, carbon dioxide, and salt; student 3/12 claimed that water was composed of a molecule of hydrogen and nitrogen; and student 4/12 believed that water was made up of atoms. Only one of the 14-year-olds (student 4/14) responded correctly to Question 1c. The incorrect answers of the 14-year-olds were, for example, that water is composed of hydrogen and carbon (student 1/14), of oxygen and hydrogen (students 2/14 and 3/14), and of water (student 5/14). Among the 16-year-olds, two students (3/16 and 4/16) provided the correct answer to Question 1c, with the incorrect respondents including three students (1/16, 2/16 and 5/16) who answered that water (the macroscopic level) consisted of one oxygen atom and two hydrogen atoms (the submicroscopic level).

All of the students correctly recognized water in the photo as being in the solid state (Question 1d). Of the three animations offered, all of the students correctly chose the one that illustrated water in the solid state (Question 1e).

Question 1f asked the students to argument their answer to Question 1e, and was supposed to be answered at the submicroscopic level. The correct answer at the particulate level is that water molecules are correctly and periodically distributed in ice, that the spacing of the molecules is the same in every direction, and that each molecule has identical surroundings. The hydrogen bonds result in spaces between the water molecules. In the crystal structure of ice, water molecules rotate around their own axes (oscillation). Table 1 shows that none of the 12-year-olds gave appropriate reasons for their decisions. At the particulate level, two correct reasons were

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

provided by one 14-year-old (student 5/14), and by three 16-year-olds (students 2/16, 3/16 and 4/16). Students 2/12, 3/12, 4/12, 2/14, 3/14 and 5/16 gave answers that were still acceptable because they included a comparison of the speed of the molecular motion in the three animations offered. The students' wrong answers attest to their misunderstanding of the static particles in the solid state. Student 1/16 assigned macroscopic properties (a molecule has an orderly structure) to water molecules.

Table 1. The students' answers to the first authentic task; a correct answer is marked with a circle, a wrong answer is marked with a circle with a vertical line, and a partly correct answer is marked with a circle with a dot.

		Student														
Question	**Answer**	**1/12**	**2/12**	**3/12**	**4/12**	**5/12**	**1/14**	**2/14**	**3/14**	**4/14**	**5/14**	**1/16**	**2/16**	**3/16**	**4/16**	**5/16**
1a	Ice	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
1b	Water	○	○	○	○	○		○		○	○	○	○		○	○
	Other (wrong)						⦶		⦶					⦶		
1c	Water molecules									○				○	○	
	Other (wrong)	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶		⦶	⦶	⦶			⦶
1d	Solid	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
1e	Correct selection 1	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
1f	Motion of particles										○		○	○	○	
	Other (still acceptable)		⊙	⊙	⊙			⊙	⊙							⊙
	Other (wrong)	⦶				⦶	⦶			⦶		⦶				

The second authentic task (Figure 3) was related to the recognition of the liquid state of water. The students were asked to identify running water in the photo and, from three animations, to select the appropriate distribution of water molecules in the liquid state at the particulate level. They also had to justify their selection.

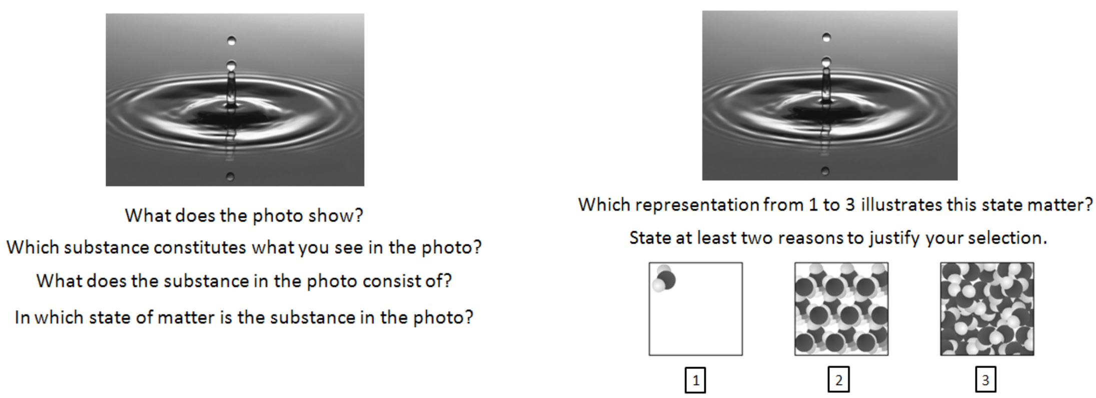


Figure 3: Screen images of the second authentic task.

(Image of Flowing water from *www.goingmobo.com*).

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

As is evident from Table 2, all of the students were able to identify running water (Question 2a). All but two of the students answered Question 2b correctly, i.e., they identified that the substance in the photo was water. Student 1/14 stated that water was composed of two hydrogen atoms and one carbon atom, while student 2/14 believed that water was composed of hydrogen and oxygen (the macroscopic level).

The correct answer to Question 2c was water molecules. The 12-year-olds failed to provide the expected response; they mentioned atoms in their responses (students 1/12, 4/12 and 5/12), as well as giving other answers (student 2/12: oxygen, CO_2, and salt; student 3/12: I do not know the substances). Of the 14-year-olds, two students failed to give the correct answer: student 1/14 stated water in his response, whereas student 3/14 opted for oxygen and hydrogen. Two 16-year-olds failed to give the correct answer: student 1/16 answered that water consisted of two hydrogens and one oxygen, while student 2/16 stated that it was made up of two hydrogen atoms and one oxygen atom. It is evident that, as in the first task, two types of wrong answers were given to the Question 2c in the second task, which required an answer at the submicroscopic level (water molecules): at the submicroscopic level – atoms (wrong particles) – and at the macroscopic level – water, oxygen, matter.

All of the students answered correctly that water in the photo was in the liquid state (Question 2d), and they all chose the correct water animation at the particulate level for the representation of water in the photo (Question 2e).

Question 2f asked the students to justify their answer to Question 2e, and was supposed to be answered at the submicroscopic level. The expected answer is that water molecules are arranged in a relatively orderly way, but the distribution of the moving molecules is not permanent; there are strong attractive forces between water molecules, but molecules may move. Table 2 shows that none of the 12- or 14-year-olds provided at least two valid reasons for the arguments at the particulate level, while two correct reasons at the particulate level were provided by three 16-year-olds (students 2/16, 3/16 and 4/16). Students 2/12, 3/12, 4/12, 5/12, 1/14, 2/14, 3/14, 5/14 and 5/16 gave answers that were still acceptable because they included a comparison of the speed of the molecules in the three animations offered. When justifying her selection, student 4/12 referred to the fact that she had already learned the topic in school. When justifying the selection of the animation of the liquid state of water, three students incorrectly claimed that the presented particles adopted the form of a container (Table 2, Question 2f), which reveals their misunderstanding of the macroscopic and submicroscopic levels.

Table 2. The students' answers to the second authentic task; a correct answer is marked with a circle, a wrong answer is marked with a circle with a vertical line, a partly correct answer is marked with a circle with a dot.

		Student														
Question	**Answer**	**1/12**	**2/12**	**3/12**	**4/12**	**5/12**	**1/14**	**2/14**	**3/14**	**4/14**	**5/14**	**1/16**	**2/16**	**3/16**	**4/16**	**5/16**
2a	Water	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
2b	Water	○	○	○	○	○			○	○	○	○	○	○	○	○
	Other (wrong)						⦶	⦶								
2c	Water molecules							○		○	○			○	○	○
	Other (wrong)	⦶	⦶	⦶	⦶	⦶	⦶		⦶			⦶	⦶			
2d	Liquidus	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
2e	Correct selection 3	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
2f	Motion of particles												○	○	○	
	Other (still acceptable)		⊙	⊙	⊙	⊙	⊙	⊙	⊙		⊙					⊙
	Other (wrong)	⦶								⦶		⦶				

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

The third authentic task (Figure 4) concerned the identification of the gaseous state of water. The students were asked to identify steam in the displayed photo and, from three animations, to select the appropriate distribution of water molecules in the gaseous state at the particulate level. They were also asked to justify their decision.

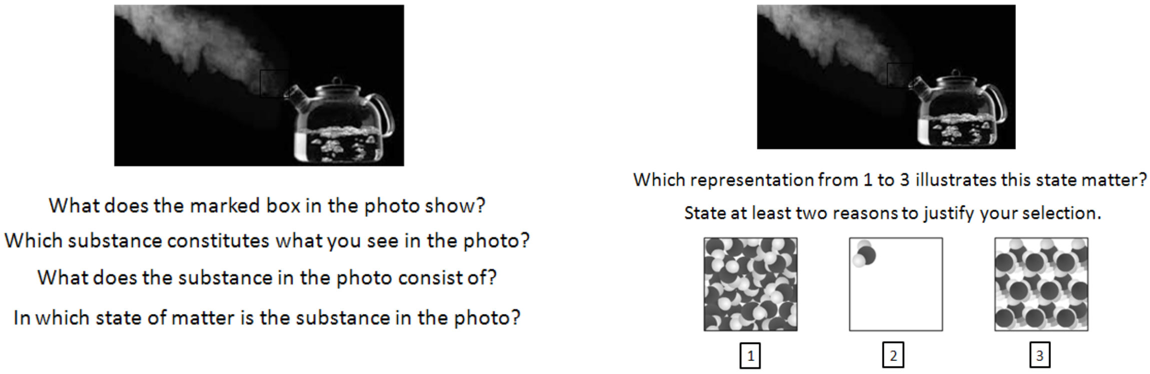


Figure 4: Screen images of the third authentic task.

(Image of Kettle with water from *www.tuttnauer.com*).

As is evident from Table 3, all of the students were able to identify steam (Question 3a). They all answered Question 3b correctly, except for one student (1/14), who stated that water was composed of carbon (the correct answer to Question 3c is water molecules). Table 3 shows that three of the 12-year-olds, three of the 14-year-olds, and all of the 16-year-olds gave the expected answer. During the interview pertaining to the third authentic task, some of the students managed to identify water molecules independently. The incorrect answers were similar to those given in the first and second tasks (Question 3b): at the submicroscopic level – atoms (student 1/12) – and at the macroscopic level – substances that make up water (student 2/12), carbon (student 1/14), and hydrogen and oxygen (student 3/14). Question 3c of the third task, which required an answer at the submicroscopic level, was also answered at the macroscopic level, as was the case in the first and second tasks. All of the students answered correctly that the water in the photo is in the gaseous state (Question 3d), and they all chose the correct steam animation at the particulate level for the representation of water in the photo (Question 3e).

Question 3f required the students to argument their answers to Question 3e, and was supposed to be answered at the submicroscopic level. The correct answer at the particulate level is that water molecules in the gaseous state move freely, there are no attraction forces between them, and the speed of the molecules' movement is high. The distances between the molecules are large, and they are not arranged in an orderly way, instead moving in the whole area at their disposal. Table 3 shows that student 3/14 was the only one to give two appropriate reasons at the submicroscopic level (the distance between the molecules and their speed of movement). When justifying the selection of the animation of the gaseous state of water, four students (5/12, 4/14, 5/14 and 5/16) stated that the molecules were moving freely, whereas students 4/12, 2/14, 2/16 and 3/16 responded that the molecules moved fastest in the selected animation. The incorrect answers may be classified into two groups: (a) the description of the submicroscopic level with the macroscopic level (student 1/12: the particles are light and are mixed with air; student 3/12: the molecules are rare; student 4/16: the water goes up and moves freely), and (b) misconceptions within the submicroscopic level (student 2/12: the atoms collide with each other; student 1/14: the atoms do not collide with each other; student 1/16: there is space between the atoms).

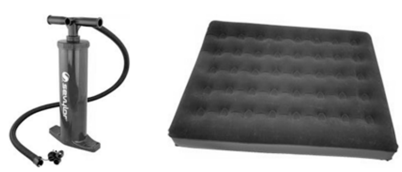
ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table 3. The students' answers to the third authentic task; a correct answer is marked with a circle, a wrong answer is marked with a circle with a vertical line, a partly correct answer is marked with a circle with a dot.

		Student														
Question	**Answer**	**1/12**	**2/12**	**3/12**	**4/12**	**5/12**	**1/14**	**2/14**	**3/14**	**4/14**	**5/14**	**1/16**	**2/16**	**3/16**	**4/16**	**5/16**
3a	Steam	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
3b	Water	○	○	○	○	○		○	○	○	○	○	○	○	○	○
	Other (wrong)						⦶									
3c	Water molecules			○	○	○		○		○	○	○	○	○	○	○
	Other (wrong)	⦶	⦶				⦶		⦶							
3d	Gaseous	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
3e	Correct selection 2	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
3f	Motion of particles								○							
	Other (still acceptable)				⊙	⊙		⊙		⊙	⊙		⊙	⊙		⊙
	Other (wrong)	⦶	⦶	⦶			⦶					⦶			⦶	

The fourth authentic task (Figure 5) considered the warming of air in a pump. Based on the photo and their everyday experience, the students were asked to connect the process of compressing and heating air with the selection of the appropriate animation (three animations were offered). They were also asked to justify their selection.

You have gone to visit your aunt on vacation. Since there is no bed available, you are going to sleep on an air mattress. You will use the pump in the photo to inflate the mattress.



Which substance will you use to fill the mattress with the pump in the photo?

You have gone to visit your aunt on vacation. Since there is no bed available, you are going to sleep on an air mattress. You will use the pump in the photo to inflate the mattress.

What is happening to the air in the pump?

When using the pump in the photo, you will see that the contents of the pump are heated.

Which of the representations at the particulate level shows what happens to the particulate matter in the pump, when the temperature increases? Justify your selection of the representation.

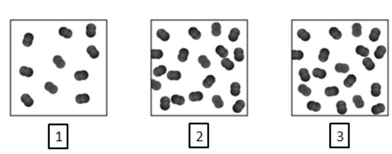


Figure 5: Screen images for the fourth authentic task.

(Image of Air pump from *www.ideo.si*).

Table 4 shows the students' answers to the questions in the fourth authentic task. The use of the pump referred to in the fourth authentic task had not been presented to the students at school. All of the students answered correctly that the airbed was filled with air using an air pump (Question 4a), except for one (1/14), who stated that the airbed was inflated with carbon dioxide using a pump. Question 4b concerned what was happening to the air in the air pump, i.e., which of its properties were being changed. The expected response was that the volume of air was reduced, whereby the air was also heated. In cases where the student mentioned only one reason, the answer is still marked as acceptable in Table 4. Seven students (1/12, 2/12, 3/12, 1/14, 1/16, 3/16, 5/16) failed to answer the question directly, and, despite encouragement, concentrated on the flow of air from the air pump into the airbed, as well as on a description of the process of filling the airbed with air, which was considered a wrong answer.

In the fourth authentic task, Question 4c required students to select the correct animation of air at the particulate level, when compressed in an air pump. In the animation, the air at the particulate level was represented by nitrogen molecules (in blue) and oxygen molecules (red), whereby the volume ratio and size of the molecules were considered. In their observations, the students were required to pay attention to the speed of movement of the particles and to the number of particles in the given space (density). The correct animation (marked No. 1) was chosen by two 12-year-olds (students 1/12 and 4/12), one 14-year-old (student 2/14), and four 16-year-olds (students 1/16, 2/16, 3/16 and 4/16). The animation marked No. 2, showing the reduction of particles in the case of compressed air, was an incorrect selection and was chosen six times (students 2/12, 3/12, 5/12, 4/14, 5/14 and 5/16), while the animation marked No. 3, showing the slowed down movement of particles when air is compressed, was also incorrect and was selected once (student 1/14).

The students justified their selection of the correct animation (Question 4d) by their observations that the movement of particles was faster and their number per unit volume was greater. Misconceptions can also be recognized among the responses. Students 2/12, 3/12, 4/14, 5/14 and 5/16 argued that the particle size decreased during heating. One student (3/14) stated that the distance between the particles was greater at higher temperatures, which is not the correct answer in this case. Two students (5/12 and 1/14) stated that the red particles were warmer than the blue ones. When addressing heat and temperature, the colors red and blue are generally used to illustrate areas of higher and lower temperatures, respectively.

Table 4. The students' answers to the third authentic task; a correct answer is marked with a circle, a wrong answer is marked with a circle with a vertical line, a partly correct answer is marked with a circle with a dot.

		Student														
Question	Answer	1/12	2/12	3/12	4/12	5/12	1/14	2/14	3/14	4/14	5/14	1/16	2/16	3/16	4/16	5/16
4a	Air	○	○	○	○	○		○	○	○	○	○	○	○	○	○
	Other (wrong)						⦶									
4b	Reduced volume and a higher temperature							○	○							
	Other (still acceptable)			⊙	⊙	⊙				⊙	⊙		⊙		⊙	
	Other (wrong)	⦶	⦶				⦶					⦶		⦶		⦶
4c	Correct selection 1	○			○			○	○			○	○	○	○	
	Wrong selection		⦶	⦶		⦶	⦶			⦶	⦶					⦶
4d	Correct justification	○			○			○				○	○	○	○	
	Other (wrong)		⦶	⦶		⦶	⦶		⦶	⦶	⦶					⦶

The students also graded the difficulty of each task solved. Table 5 shows that their assessment of the first three tasks ranged from very easy to moderately difficult, while the fourth task was assessed from moderately difficult to

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

very difficult. These ratings are also reflected in the answers of the students, which are incorrect but still acceptable.

Table 5. The student's assessment of the difficulty of the authentic tasks.

	Very easy		Easy			Moderately difficult			Difficult			Very difficult	
Task 1	4/14	1/16	1/12	3/14		3/12	1/14						
		2/16	2/12	5/14			2/14						
		3/16	4/12										
		4/16	5/12										
		5/16											
Task 2	4/14	1/16	1/12	1/14	4/16		2/14		4/12				
	5/14	2/16	2/12	3/14	5/16								
		3/16	3/12										
			4/12										
Task 3	4/14	1/16	2/12	2/14	5/16	1/12	1/14						
	5/14	2/16	3/12	3/14									
		3/16	4/12										
		4/16	5/12										
Task 4					1/16	1/12	4/14	2/16	3/12	1/14	5/16	5/12	2/14
						2/12		3/16	4/12				3/14
								4/16					5/14

Discussion

The research results show how students of different ages respond to questions in tasks related to the states of water and air, and what misconceptions are identified in solving authentic tasks concerning the state of water and air, and the properties of gases. The answers are formed with regard to the research questions established.

RQ1: What are the misconceptions in students of various age groups in solving authentic tasks that include animations at the macroscopic and submicroscopic levels of the physical states of water and air?

It was established that all of the research respondents recognize the submicroscopic representation of water molecules in the respective physical state of water (Tables 1, 2 and 3). When justifying the selection of the appropriate representation, however, students have problems related to the description of the submicroscopic level with the macroscopic level, as well as misconceptions within the submicroscopic level. The respondents experience fewer problems as they move vertically through the education system, as confirmed by the results of the first and second authentic tasks (Table 1 and Table 2). However, this progress is not evident in solving the third authentic task, which was trivial (Table 3) in comparison with the first two tasks. It was clear that the students' interest in justifying their selection declined in the third task; this was evident from the many sub-questions posed by the researcher in an effort to stimulate them. As expected, the 16-year-olds were more successful in identifying the submicroscopic representation of air at the particulate level in the fourth task (Table 4).

In Slovenian schools, 10-year-old students are already familiar with the physical state of water and need to be able to describe the physical states of water and their properties (Balon et al. 2011) at the macroscopic level. Students become more familiar with water and its structure at the submicroscopic level as they move vertically through the education system. Eleven-year-olds upgrade their acquired knowledge and link it with submicroscopic representations of the composition of water. Kind (2004) believes that the particulate nature of the states of matter is most often explained using the example of water. She also highlights the difficulties that arise in the application of the acquired knowledge to other examples; this fact was also established in our study, as only half of the students (two 12-year-olds, two 14-year-olds and four 16-year-olds) chose the correct submicroscopic representation of air in the fourth task (Table 4). One possible reason for this is that the particles are different, whereas they are the same in the case of water (first, second and third authentic tasks; Table 1, 2 and 3). In the first three authentic tasks, the students were asked to determine the physical state of water based on the submicroscopic representation of water molecules, which is also the operational learning goal of the science subject (11-year-olds) (Skvarč et al., 2011). The research confirmed that 12-year-olds had already achieved this operational learning objective. The students' assessment of the difficulty of the first three authentic tasks (Table 5) attests to their knowledge of the explanation of the physical states of matter in the case of water. The first three authentic tasks tested reproductive knowledge. When creating animations of the fourth authentic task, related to air in a pump (Figure 5), the research findings of previous research (Novick & Nussbaum, 1981; Kind, 2004; Rahayu & Kita, 2010; Mumba et al. 2014) were taken into account. The content of this authentic task is not identified in textbooks; moreover, students have to be capable of observing two or more variables at the same time in particulate matter animations. The intentionally changed parameters in the animations are as follows: (a) reduction/increase in the number of particles per area unit, (b) reduction/increase in the speed of particle movement, or (c) reduction in the volume of the individual particle of the substance. This task therefore tested the higher cognitive levels of the students' understanding. In students of all age groups, misunderstandings were established in relation to the reduction of particles when air is compressed (Table 4), which is consistent with the results of the aforementioned research.

The expected answer to Question c of the first, second and third authentic tasks (Figures 2, 4 and 6) – "What is the substance in the photo composed of?" – was "of water molecules". At the macroscopic level, the students gave the following answers: of water, of oxygen and hydrogen, of two hydrogens and one oxygen, and of oxygen, CO_2, and salt; at the submicroscopic level, their answers were: of two hydrogen atoms and one oxygen atom, and of atoms. It is evident that the students did not distinguish between the levels to which the questions referred, as questions requiring an answer at the submicroscopic level were answered at the macroscopic level. The results are consistent with the findings of Pereira & Pestana (1991), which suggest that students visualize the states of water at the macroscopic level. The research results are consistent with the findings of other studies (Harrison & Treagust, 2000; Nicoll, 2001; Chiu et al., 2002), which show that students frequently assign macroscopic properties to particulate matter, thus revealing their misconceptions regarding the macroscopic and submicroscopic levels of particulate matter representations. The students in the present study wrongly answered that water was composed of two different substances (hydrogen and oxygen), which suggests their misunderstanding of the distinction between the particulate matter of which water is composed (a water molecule) and two different substances (the elements of hydrogen and oxygen). Since the correct answer to the question "What is water composed of?" is "of water molecules", the students' responses stating that water was composed of two hydrogen atoms and one oxygen atom, or that water was composed of atoms, were considered incorrect. The reason for this is the incorrect definition of the type of particulate matter. The response that water is composed of oxygen, CO_2 and salt indicates that the students addressed water at the macroscopic level, as a solution of various substances, failing to take into account the particles of which water is composed.

Perceived misconceptions related to the physical properties of particulate matter were: reduction/increase in particulate matter, changing the color of particulate matter, changing the shape of particulate matter, and the speed of movement of particulate matter. Similar misconceptions were reported in the results of an earlier survey (Kind, 2004), which suggested that a small proportion of 16-year-olds used a particle model of matter for the interpretation of the physical and chemical properties of matter. Some 16-year-olds believe that gas particles expand when gas is heated. Novick and Nussbaum (1981) report that 40 percent of 16-year-olds believe that the key reason for gas heating is the faster movement of particulate matter. This result indicates a significant proportion of students who do not know how to explain gas heating at the level of particulate matter, which has also been confirmed by research on the misunderstanding of science concepts at the submicroscopic level, including the physical state of matter (Chiu et al., 2002; Mulford, & Robinson, 2002; Vermaat et al., 2003; Devetak, Vogrinc & Glažar, 2009; Devetak, 2009; Mumba et al. 2014).

The simultaneous distinction and connection of the macroscopic and submicroscopic levels of a substance is fundamental to the creation of an appropriate mental model of the science concept. Only properly designed mental models enable students a comprehensive understanding of science learning content. In terms of the awareness of teachers, it is essential to know that switching between the macroscopic level and the submicroscopic level is generally difficult for students. Researchers Van Driel, Jong and Verloop (2002) argue that many teachers are not even aware of this problem, and highlight the need to ensure that future teachers take account of these problems regarding content at the particulate level. They also emphasize the importance of the careful and consistent use of language.

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

Many researchers (Barker & Millar, 2000; Kind, 2004; Ferk Savec, Vrtačnik & Gilbert, 2005; Mumba et al., 2014; Herga et al., 2015; Herga, Čagran & Dinevski, 2016) point out that students have difficulty understanding the particulate nature of matter due to the invisibility of particles in matter. To overcome this, an important role is attributed to the visualization of science concepts, which should be a focus in the education of future teachers, and at workshops for practicing teachers. It is up to teachers to gradually accustom students to submicroscopic matter representations, and to confront them with diverse cases, so that they do not merely identify what is already known to them.

RQ2: At what level of the representation of science concepts (macroscopic/submicroscopic) do students argument their selection of the appropriate animation with a submicroscopic representation of particles of water and air?

The students answered the open-type questions (1f, 2f, and 3f and 4d), which required the justification of the selection of the appropriate animation of the submicroscopic representation of the physical state of water and air, both at the macroscopic and the submicroscopic levels of particulate matter. From Tables 1, 2 and 3, it is evident that all of the students chose the correct representation of the physical state of water at the particulate level. However, when choosing the representation that showed the change in compressed air, it is clear that not all of the students selected the correct representation.

In the answer to Question 1f, all of the students except one justified their selection at the submicroscopic level (Table 1), which was the expected response. Furthermore, in response to Question 2f (Table 2) all of the students justified their selection at the submicroscopic level, with some of the students' answers also attesting to their macroscopic observations, which could not be based on the representations of particulate matter motion ("if particles are put into a container, they adopt the shape of a container"/"a plane is created"/"particles are more densely distributed than ice"/"particles move differently from gas and a solid substance"/"atoms move more than in the solid state, atoms do not form a solid substance").

Similar findings were established in the responses to Question 3f (Table 3). Some students pointed out that particles are light and can therefore mix with air/particles do not have a fixed form/ the fewest molecules are drawn in the gaseous state, as water has sufficient energy to move upwards and moves freely/molecules are sparsest/ atoms move freely, there is a lot of space between them.

As mentioned above, the students experienced difficulty in choosing the correct submicroscopic representations of compressed air, and consequently also in the justification of their selection of the appropriate particle representation of air (Question 4d). Among the answers of the students, arguments at the macroscopic level (red atoms are warmer than the blue ones/the movement of the particles is accelerated because it is hot, there are more particles, the particles are getting closer together) are again identified, which attests to the students' misconceptions. The results of our study are consistent with the results of earlier studies (Pereira & Pestana, 1991; Mumba et al., 2014) suggesting that students aged 13 years perceive the physical states of water as macro phenomena (water surface drawing).

Failure to distinguish between the macroscopic and submicroscopic levels of matter representation is evident from the results of previous research (Harrison & Treagust, 2000; Nicoll, 2001; Chiu et al., 2002; Ferk Savec et al., 2005; Mumba et al., 2014; Herga et al., 2015; Herga et al., 2016). The results of the present research are consistent with the findings of earlier research and confirm that explanation of the submicroscopic level of representation with macroscopic observations is identified in students of different age groups.

Conclusions

The aim of this research was to determinate the level of knowledge of the states of water and air of the participating students aged 12, 14 and 16 years, highlighting the identified misconceptions of this topic. It can be concluded that students' misconceptions do not change significantly over the years of science education. The most frequent difficulties students show the misconceptions regarding: (a) the interpretation of the particulate nature of matter at the, (b) the failure to distinguish between particles and matter at the macro level, and (c) the description of the submicroscopic level of matter using macroscopic concepts. It is shown that there are in all age groups students having difficulties to apply gained knowledge to new situations – the case of air pump. This study indicates that teachers should present the learning content with carefully chosen examples from different contexts that illustrate specific concept at all levels of representations.

Even though the questions for the semi-structured interview, the tasks and the animations were carefully prepared, they still need to be improved with further optimization. When observing animations, there is also a question of the number of different variables it is possible for students of different age groups to monitor simultaneously, not to overload students' working memory, in terms of: (a) the student's information processing, and (b) the appropriateness of the teacher's presentation of the learning content during instruction. In the present research, data are collected from 15 primary and secondary school students. This could also limit the conclusions although the study was qualitative.

The present research raises guidelines for further qualitative and quantitative research into the content of the state of matter, with a focus on: (a) how various everyday life contexts, (b) how authentic tasks and problems of varying levels of difficulty, (c) how an increased number of variables in animations, (d) how previous experience with solving such tasks, (e) how the level of formal-reasoning abilities and (f) how the number of substantially similar tasks, influence problem solving.

Acknowledgements

This research was supported by the project Explaining Effective and Efficient Problem Solving of the Triplet Relationship in Science Concepts Representations (J5-6814), financed by the Slovenian Research Agency (ARRS).

Note

Photo references:

Photo "Iceberg" (First authentic task, photo 2): hdwpics.com
Photo "Flowing water" (Second authentic task, photo 4): www.goingmobo.com
Photo "Kettle with water" (Third authentic task, photo 6): www.tuttnauer.com
Photo "Air pump" (Fourth authentic task, photo 8): www.ideo.si

References

Bačnik, A., Bukovec, N., Poberžnik, A., Požek Novak, T., Keuc, Z., Popič, H., & Vrtačnik, M. (2009). *Učni načrt. Učni načrt, Program srednja šola, Kemija: gimnazija: klasična, strokovna gimnazija: obvezni predmet (210 ur), izbirni predmet (3 x 35 ur) in matura (105 + 35 ur)*. [Curriculum. Curriculum, program of secondary school, Chemistry: gymnasium: classical, professional gymnasium: compulsory subject (210 hours), elective subject (3 x 35 hours) and the final exam (105 + 35 hours)]. Ljubljana: Zavod RS za šolstvo.

Bačnik, A., Bukovec, N., Vrtačnik, M., Poberžnik, A., Križaj, M., Stefanovik, V., Sotlar, K., Dražumerič, S., & Preskar, S. (2011). *Učni načrt. Program osnovna šola. Kemija* [Curriculum. Program of primary school. Chemistry]. Ljubljana: Zavod RS za šolstvo.

Balon, A., Gostinčar Blagotinšek, A., Papotnik, A., Skribe Dimec, D., & Vodopivec, I. (2011). *Učni načrt. Program osnovna šola. Naravoslovje in tehnika.* [Curriculum. Program of primary school. Natural science and technology]. Ljubljana: Zavod RS za šolstvo.

Barker, V., & Millar, R. (1999). Students' reasoning about thermodynamics and chemical bonding: What changes occur during a context-based post-16 chemistry course? *International Journal of Science Education*, *21* (6), 645-665.

Bunce, D. M., & Gabel, D. (2002). Differential effects in the achievement of males and females of teaching the particulate nature of chemistry. *Journal of Research in Science Teaching, 39* (10), 911–972.

Chittleborough, G. (2014). The development of theoretical frameworks for understanding the learning of chemistry. In I. Devetak and S. A. Glažar (eds.), *Learning with understanding in the chemistry classroom* (pp. 25–40). Dordrech: Springer.

Chiu, M. L., Chiu, M. H., & Ho, C. Y. (2002). Using cognitive-based dynamic representations to diagnose students' conceptions of the characteristics of matter. *Proceedings of the National Science Council, 12* (3), 91-99.

Devetak, I. (2005). *Pojasnjevanje latentnega prostora razumevanja submikroreprezentacij v naravoslovju.* Doktorska disertacija. [Explaining the latent structure of understanding submicrorepresentations in science. Ph.D. Thesis]. Ljubljana: Pedagoška fakulteta Univerze v Ljubljani.

Devetak, I. (2012). *Zagotavljanje kakovostnega znanja naravoslovja s pomočjo submikroreprezentacij. Analiza ključnih dejavnikov zagotavljanja kakovosti znanja v vzgojno – izobraževalnem sistemu.* [The analysis of the key factors in ensuring the quality of knowledge in educational system]. Ljubljana: Pedagoška fakulteta Univerze v Ljubljani.

Devetak, I., Drofenik Lorber, E., Juriševič, M., & Glažar, S. A. (2009). Comparing Slovenian year 8 and year 9 elementary school pupils' knowledge of electrolyte chemistry and their intrinsic motivation. *Chemistry Education Research and Practice, 10* (4), 281-290.

Devetak, I., & Glažar, S. A. (2011). Teachers' influence on students' motivation for learning science with understanding. In R. V. Nata, (ed.), *Progress in education*, Vol. 19 (pp. 77-103). New York: Nova Science Publishers.

Devetak, I., & Perdih, F. (2012). *Kemija 1, učbenik za kemijo v 1. letniku gimnazij* [Chemistry 1, textbook for chemistry in the 1st year of gymnasium]. Ljubljana, Mladinska knjiga.

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

Devetak, I., Vogrinc, J., & Glažar, S. A. (2009). Assessing 16-year-old students' understanding of aqueous solution at submicroscopic level. *Research in Science Education, 39* (2), 157-179.

Falvo, D. A., Urban, M. J., & Suits, J. P. (2011). Exploring the impact of and perception about interactive, self-explaining environments in molecular-level animation. *CEPS Journal, 1* (4), 45-61.

Ferk Savec, V., Vrtačnik, M., & Gilbert, J. K. (2005). Evaluating the educational value of molecular structure representations. In J. K. Gilbert, (ed.), *Visualization in science education*, (Models and modeling in science education, Vol. 1) (pp. 269-300). Dordrecht: Springer.

Georgiadou, A., & Tsaparlis, G. (2000). Chemistry teaching in lower secondary school with methods based on: A) Psychological theories; B) The macro, representational, and submicro levels of chemistry. *Chemistry Education: Research and Practice in Europe, 1* (2), 217–226.

Gregorius, R. M., Santosb, R., Danob, J. B., & Gutierreb, J. J. (2010). Can animations effectively substitute for traditional teaching methods? Part I: Preparation and testing of materials. *Chemistry Education Research and Practice, 11* (4), 253-261.

Harrison, A. G., & Treagust, D. F. (2000). Learning about atoms, molecules, and chemical bonds: A case study of multiple–model use in grade 11 chemistry. *Science Education, 84* (3), 352–381.

Herga, N. R., Čagran, B., & Dinevski, D. (2016). Virtual laboratory in the role of dynamic visualisation for better understanding of chemistry in primary school. *EURASIA Journal of Mathematics, Science and Technology Education*, *12* (3), 593-608.

Herga, N. R., Glažar, S. A., & Dinevski. D. (2015). Dynamic visualization in the virtual laboratory enhances the fundamental understanding of chemical concepts. *Journal of Baltic Science Education, 14* (3), 351-365.

Johnstone, A. H. (1982). Macro- and micro- chemistry. *School Science Review, 64* (227), 377–379.

Kind, V. (2004). *Beyond appearances*: *students' misconceptions about basic chemical ideas*, 2nd edition. Durham: Durham University, School of Education.

Lee, O., Eichinger, D. C., Anderson, C. W., Berkheimer, G. D., & Blakeslee, T. D. (1993). Changing middle school students' conceptions of matter and molecules. *Journal of Research in Science Teaching, 30* (3), 249-270.

Limniou, M., Papadopoulos N., & Whitehead, C. (2009). Integration of simulation into prelaboratory chemical course: computer cluster versus WebCT. *Computers & Education, 52* (1), 45-52.

Moreno, R., & Mayer, R. E. (2000). A learner-centered approach to multimedia explanations: Deriving instructional design principles from cognitive theory. *Interactive Multimedia Electronic Journal of Computer-enhanced Learning, 2*, 78–107.

Mulford, D. R., & Robinson, W. R. (2002). An inventory for alternative conceptions among first-semester general chemistry students. *Journal of Chemical Education, 79* (6), 739-744.

Mumba, F., Chabalengula, V. M., & Banda, A. (2014). Comparing male and female pre-service teachers' understanding of the particulate nature of matter. *Journal of Baltic Science Education*, *13* (6), 821-827.

Nicoll, G. (2001). A report of undergraduates' bonding misconceptions. *International Journal of Science Education, 23* (7), 707-730.

Novick, S., & Nussbaum, J. (1981). Pupils' understanding of the particulate nature of matter. An interview study. *Science Education*, *62* (2), 187-196.

Olakanmi, E., E. (2015). The effects of a web-based computer simulation on students' conceptual understanding of rate of reaction and attitude towards chemistry. *Journal of Baltic Science Education, 14* (5), 627-640.

Özmen, H. (2013). A cross – national review of the studies on the particulate nature of matter and related concepts. *Eurasian Journal of Physics and Chemistry Education, 5* (2), 81-90.

Pereira, M. P., & Pestana, M. E. M. (1991). Pupils' representations of models of water. *International Journal of Science Education, 13* (3), 313-319.

Planinšič, G., Belina, R., Kukman, I., & Cvahte, M. (2009). *Učni načrt, Program srednja šola, Fizika: gimnazija: klasična, strokovna gimnazija: obvezni predmet (210 ur), izbirni predmet (3 x 35 ur) in matura (105 + 35 ur)*. [Curriculum. Curriculum, program of secondary school, Physics: gymnasium: classical, professional gymnasium: compulsory subject (210 hours), elective subject (3 x 35 hours) and the final exam (105 + 35 hours)]. Ljubljana: Ministrstvo za šolstvo in šport: Zavod RS za šolstvo.

Rahayu, S., & Kita, M. (2010). An analysis of Indonesian and Japanese students' understandings of macroscopic and submicroscopic levels of representing matter and its changes. *International Journal of Science and Mathematics Education*, *8* (4), 667-688.

Rodrigues, S., Smith, A., & Ainley, M. (2001). Video clips and animation in chemistry CD-Roms: student interest and preference. *Australian Science Teaching Journal, 47* (2), 9-16.

Sarabando, C., Cravino, J. P., & Soares, A. A. (2016). Improving student understanding of the concepts of weight and mass with a computer simulation. *Journal of Baltic Science Education, 15* (1), 109-126.

Skvarč, M., Glažar, S. A., Marhl, M., Skribe Dimec, D., Zupan, A., Cvahte, M., Gričnik, K., Volčini, D., Sabolič, G., & Šorgo, A. (2011). *Učni načrt. Program osnovna šola. Naravoslovje.* [Curriculum. Program of primary school. Science]. Ljubljana: Zavod RS za šolstvo.

Stavy, R. (1988). Children's conceptions of gas. *International Journal of Science Education*, *10* (5), 553-560.

Stern, L., Barnea, N., & Shauli, S. (2008). The effect of a computerized simulation on middle school students' understanding of the kinetic molecular theory. *Journal of Science Education and Technology, 17* (4), 305-315.

Taber, S. K. (2013). Revisiting the chemistry triplet: drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemistry Education Research and Practice, 14* (2), 156–168.

Tóth, Z., & Kiss, E. (2006). Using particulate drawings to study 13 - 17 years olds' understanding of physical and chemical composition of matter as well as the state of matter. *Practice and Theory in Systems of Education,* (1), 109–125.

Vermaat, H., Terlouw, C., & Dijkstra, S. (2003). Multiple representations in web-based learning of chemistry concepts. 84th *Annual meeting of the American Educational Research Association.* Chicago.

Verovnik, I., Bajc, J., Beznec, B., Božič, S., Brdar, U. V., Cvahte, M., Gerlič, I., & Munih, S. (2011). *Učni načrt. Program osnovna šola. Fizika* [Curriculum. Program of primary school. Physics]. Ljubljana: Zavod RS za šolstvo.

Vogrinc, J. (2008). *Kvalitativno raziskovanje na pedagoškem področju* [Qualitative research in education]. Ljubljana: Pedagoška fakulteta, Univerza v Ljubljani.

Vrtačnik, M., Sajovec, M., Dolničar, D., Razdevšek-Pučko, C., Glažar, S. A., & Zupančič-Brouwer, N. (2000). An interactive multimedia tutorial teaching unit and its effects on student perception and understanding of chemical concepts. *Westminister Studies in Education, 23* (1), 91-105.

Vrtačnik, M., Wissiak Grm, K. S., Glažar, S. A., & Godec, A. (2015). *Moja prva kemija, učbenik za 8. in 9. razred osnovne šole* [My first chemistry, textbook for 8th and 9th grade of primary school]. Ljubljana: Modrijan.

Wu, H. K., Krajcik, J. S., & Soloway, E. (2001). Promoting understanding of chemical representations: Students' use of a visualisation tool in the classroom. *Journal of Research in Science Teaching, 38* (7), 821–842.

Yang, E., Andre, T., & Greenbowe, T. J. (2003). Spatial ability and impact of visualization/animation on learning electrochemistry. *International Journal of Science Education, 25* (3), 329-349.

Received: *March 12, 2017*

Accepted: *May 20, 2017*

Miha Slapničar	PhD Student and Teaching Assistant of Chemical Education, University of Ljubljana, Faculty of Education, Department of Biology, Chemistry and Home Economics, Kardeljeva ploščad 16, 1000 Ljubljana, Slovenia. E-mail: miha.slapnicar@pef.uni-lj.si Website: https://www.pef.uni-lj.si/1089.html
Iztok Devetak	PhD, Associate Professor of Chemical Education, University of Ljubljana, Faculty of Education, Department of Biology, Chemistry and Home Economics, Kardeljeva ploščad 16, 1000 Ljubljana, Slovenia. E-mail: iztok.devetak@pef.uni-lj.si Website: https://www.pef.uni-lj.si/1086.html
Saša A. Glažar	PhD, Full Professor of Chemical Education, University of Ljubljana, Faculty of Education, Department of Biology, Chemistry and Home Economics, Kardeljeva ploščad 16, 1000 Ljubljana, Slovenia. E-mail: sasa.glazar@pef.uni-lj.si Website: https://www.pef.uni-lj.si/1218.html
Jerneja Pavlin	PhD, Assistant Professor of Physics Education, University of Ljubljana, Faculty of Education, Department of Physics and Technical Studies and Department of Primary Teacher Education, Kardeljeva ploščad 16, 1000 Ljubljana, Slovenia. E-mail: jerneja.pavlin@pef.uni-lj.si Website: https://www.pef.uni-lj.si/1119.html