Croatian Journal of Education
Vol.24; No.1/2022, pages: 161-188
Original research paper
Paper submitted: 15th July 2020
Paper accepted: 14th May 2021
https://doi.org/10.15516/cje.v24i1.4115

Development of Conceptual Understanding of Physical and Chemical Changes at the Macroscopic, Submicroscopic and Symbolic Level: A Cross-Age Study

Katarina Putica
Innovative Centre of the Faculty of Chemistry, University of Belgrade

Abstract

In order to explain the development of understanding of chemical concepts at the macroscopic, submicroscopic and symbolic level over time, models of the expanding triangle and rising iceberg are proposed. In order to validate the two models, this study examined whether the depth of understanding of the concepts physical and chemical changes at each of the levels significantly changes with the age of students, whether selected age groups exhibit significant differences in understanding at the three levels, and whether findings for these age groups differ. Therefore, 121 14-year-old, 108 16-year-old and 112 19-year-old students completed the test that checked their understanding of the aforementioned concepts, at all three levels. The 16- and 19-year-old students significantly outperformed the 14-year-old students at each of the levels, while all age groups showed significantly better understanding of physical and chemical changes at the macroscopic and symbolic, in comparison to the submicroscopic level. It was concluded that, while the proposed models are generally valid, the applied teaching approaches and the composition of the chemistry curriculum have a profound impact on the development of students' conceptual understanding, at all three levels of chemistry knowledge.

Keywords: *expanding triangle model; magnesium oxidation; rising iceberg model; sublimation of water.*

Introduction

Students often perceive Chemistry as an abstract and conceptually difficult subject (Childs & Sheehan, 2009), which could be related to its intrinsic nature, i. e., the fact that chemistry knowledge exists at three distinct levels (Johnstone, 2000). The macroscopic level refers to what can be seen, touched and smelt, the submicroscopic level refers to atoms, molecules, ions and structures, while the symbolic level refers to the representational use of symbols, formulae, equations, molarity, mathematical manipulation and graphs. Since none of the three levels is superior to another, but complements one another, ensuring that students understand the role of each level and relate one level to another is an important aspect of generating understandable explanations (Treagust et al., 2003). In order to achieve this goal, while learning about new chemical concepts, students are commonly required to apply multilevel thinking. Johnstone (1991) illustrated this point with a triangle with apices labeled macro, submicro and symbolic, explaining that instead of being focused on one apex, or along one side of the triangle, Chemistry teaching is predominantly conducted inside the triangle, where students must cope with all three levels at once. Research has shown that when Chemistry is taught in such a way, learners are able to develop conceptual understanding of key chemical phenomena (Ainsworth, 2006). With this in mind, Johnstone (2000), however, questioned the logic of simultaneous introduction of all three levels to novice students. His key concern was that dealing with such an amount of new information exceeds the capacity of working memory of the human brain, which restricts the number of "chunks" of new information that can be manipulated at any given time (Miller, 1968). Although working memory does not develop more slots as learners mature, familiarity with conceptual material allows each slot to hold more information (Baddeley, 1990). This ensures that the depth of understanding of any given chemical concept, at all three levels of chemistry knowledge, grows over time (Taber, 2013). But given that the macroscopic level is the most familiar to novice students, Johnstone (2000) proposed that introductory Chemistry teaching should start from this level, which should be followed by the gradual introduction of the other two levels.

In accordance with these views, Chittleborough (2014) proposed two models in order to explain the development of students' understanding of chemical concepts at the three levels of chemistry knowledge over time, both of which refer to the Johnstone's triangle. Since most Chemistry curricula are spiral, after the initial introduction to the key chemical concepts, students go on to revisit them several times during their further schooling. Consequently, students' understanding at each corner of the triangle grows, as the learning proceeds. This causes the triangle to expand, which is why the first model is named the expanding triangle model. The second proposed model, entitled the rising iceberg model, emphasizes the sequence of use of the three levels in Chemistry teaching and its influence on the development of students' conceptual understanding. The model is founded on the triangle in which the macroscopic level is presented by the top apex, while the submicroscopic and symbolic levels are presented by the bottom two apices. A horizontal line, representing the sea level, is drawn across the triangle. The area above it is shaded and it represents the students' growing understanding. Since the macroscopic level is the most appropriate for novice students, the top apex of the triangle is always included in the teaching process, while the submicroscopic and symbolic level are only introduced when needed. Over time, more and more of these two levels can be exposed to students and, consequently, the depth of their understanding grows. In analogy to this, the horizontal line moves downward and the shaded area expands.

Evidently, the two models could represent a valuable source of information about the development of students' conceptual understanding at the three levels of chemistry knowledge. However, so far, none of the models have been validated by the results of quantitative research.

Review of literature on students' understanding of physical and chemical changes at the macroscopic, submicroscopic and symbolic level

Given that physical and chemical changes represent core chemical concepts, a vast amount of research explored students' understanding of these concepts, at the three levels of chemistry knowledge.

When it comes to the changes of the states of matter, as examples of physical changes, Rahayo and Kita (2010) investigated 15-18 years old students' sound understanding of the changes from solid to liquid, solid to gaseous and liquid to gaseous state, defining sound understanding as understanding at both the macroscopic and submicroscopic level. The greatest difficulties were found relating to the change from solid to gaseous state, as less than 25 % of the students from all selected age groups showed sound understanding of the process of naphthalene sublimation. At the same time, all students demonstrated better understanding of the three types of changes at the macroscopic, in comparison to the submicroscopic level. Students' difficulties with understanding the changes of the states of matter at the submicroscopic level have also been reported by other researchers. For example, it was noted that students aged 12-13 years struggle with understanding of the change from liquid to gaseous state at this level (Nuić & Glažar, 2015). Johnson (1998a, 1998b) found that students aged 11-14 years encounter greater difficulties with understanding the processes of evaporation and condensation in comparison to the processes of melting and freezing at the particulate level and, consequently, concluded that changes involving the gaseous state are more problematic for students.

When it comes to chemical changes, Jaber and BouJaoude (2011) concluded that the 15-year-old students' understanding of chemical reactions is usually limited to the macroscopic and symbolic level, while they confound the submicroscopic level with the macroscopic level in terms of constructs and language. A tendency of the

15-year-old students to extrapolate the bulk macroscopic properties of matter to the submicroscopic level when dealing with chemical reactions was confirmed by Chandrasegaran et al. (2007), given that the students, among other things, expressed belief that reddish-brown atoms of copper were produced in the displacement reaction between zinc and copper(II) sulfate. Furthermore, the ability to represent a chemical reaction at the symbolic level proved to be no guarantee of the ability to represent the given reaction at the submicroscopic level. For example, it was ascertained that while 65.3 % of high-school students were able to correctly represent the combustion of methane at the symbolic level, only 31.1 % drew representations of this reaction that showed appropriate understanding at the particulate level (Kern et al., 2010). It was concluded that while many students appear to master the symbolic skills necessary for correct representation of chemical reactions, they often do so by treating equations as mathematical puzzles in which the numbers on the two sides of the equation have to equal each other (Krajcik, 1991).

Previous research also reported students' difficulties with distinguishing between physical and chemical changes, at both the particulate and macroscopic level. For example, more than 65 % of students aged 16-17 years expressed belief that the submicroscopic diagram which depicts splitting one molecule of a diatomic element into two atoms of that element represents a physical change, in analogy to a piece of paper being torn to two pieces (Sunyono & Sudjarwo, 2018). When it comes to the macroscopic level, it was found that around 70 % of the 14-year-old and over 50 % of the 16-year-old students thought that diluting a strong fruit juice drink by adding water was a chemical change, while 48 % of the 14-year-old and 55 % of the 16-year-old students thought that dissolving sugar in water represents a chemical change (Schollum, 1981). It was concluded that students often make the erroneous conclusion that a physical change is, in fact, a chemical change on the basis of visual cues such as "the substance changes in color, mass and state, so it would appear to be obvious that a chemical change has taken place" (Briggs & Holding, 1986, p. 63).

Research aims

As can be seen from the literature review, no previous research examined how the depth of understanding of physical and chemical changes, at each of the three levels of chemistry knowledge, changes with the age of students/number of years of chemistry learning. Furthermore, no previous research even dealt with students' understanding of physical changes at the symbolic level. In the previous two instances, it was examined whether students of one particular age group exhibit differences in the depth of understanding of chemical changes at the macroscopic, submicroscopic and symbolic level, but no previous research referring to either physical or chemical changes examined whether these differences exist when it comes to other age groups of students or whether the findings for different age groups differ. Therefore, there is a need for research findings that could be used in order to assess and validate the previously proposed models of the expanding triangle and rising iceberg, thus providing important information about the ways in which the students' conceptual understanding of physical and chemical changes at the three levels of chemistry knowledge develops over time. Consequently, the first aim of this research was to compare the depth of conceptual understanding of physical and chemical changes, at each of the three levels of chemistry knowledge, for three selected age groups of students (the 14-year-old, 16-year-old and 19-year-old students). The second aim was to ascertain whether each of the selected age groups exhibits differences in understanding of physical and chemical changes at the macroscopic, submicroscopic and symbolic level and whether the findings for the three age groups differ among them.

Methodology

Research sample

The research sample consisted of 121 elementary school students aged 14 (median age = 169 months), 108 grammar school students aged 16 (median age = 193 months) and 112 grammar school students aged 19 (median age = 228 months) from Serbia. All students voluntarily accepted to participate in the study. At the time when it was conducted, the 14-year-old students were at the end of the seventh grade of elementary school and their first year of Chemistry learning, the 16-year-old students were at the end of the first year of grammar school and their third year of Chemistry learning, while the 19-year-old students were at the end of the fourth (final) year of grammar school and their sixth year of Chemistry learning. All grammar school students attended the natural sciences stream of study.

It should be noted that Chemistry curriculum in Serbia is spiral and that Chemistry is taught as a separate subject throughout both elementary and grammar school. Students are first introduced to the concepts of physical and chemical changes in the seventh grade of elementary school and they go on to revisit them in the first year of grammar school. The second year of grammar school is devoted to the study of inorganic chemistry, while the third and fourth year are devoted to the study of organic chemistry and biochemistry, respectively. Within the elaboration of all classes of organic, biochemical and inorganic compounds, students are able to acquire extensive knowledge about their physical and chemical properties and changes.

Data collection

The quantitative data were collected by means of the Achievement test, which was composed specifically for the purposes of this study. The test consisted of two main items and students were given 45 minutes to complete it. Item 1 (I1) checked students' understanding of the sublimation of water, as an example of a physical change, while Item 2 (I2) checked their understanding of the reaction of magnesium oxidation, as an example of a chemical change. Both items consisted of three subitems (one subitem for each level of chemistry knowledge).

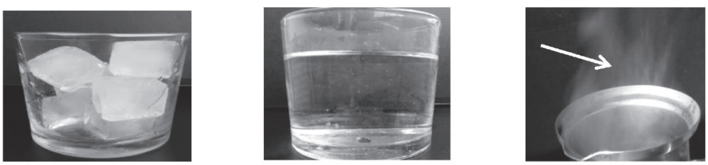
Difficulty indices for the six subitems within the Achievement test ranged from 0.32 to 0.61 for the 14-year-old students, from 0.49 to 0.75 for the 16-year-old students and from 0.61 to 0.79 for the 19-year-old students. Discrimination indices ranged from 0.35 to 0.68 for the 14-year-old students, from 0.42 to 0.66 for the 16-year-old students and from 0.39 to 0.71 for the 19-year-old students. Since all the values of the difficulty and discrimination indices are within the acceptable range of 0.3-0.8 (Peterson et al., 1989), it was concluded that the level of difficulty and the discrimination power of the Achievement test are satisfactory. Furthermore, Cronbach's alpha was used as a measure of the test reliability and its value was 0.76 for the test completed by the 14-year-old students, 0.74 for the test completed by the 16-year-old students and 0.78 for the test completed by the 19-year-old students. Given that all the values are above the lowest acceptable value of 0.70 (Cronbach, 1951), it was concluded that the test is reliable.

Full contents of the two items in the Achievement test are presented in Figure 1 and Figure 2.

11a) select the correct symbolic representation of the sublimation of water:

1) $H_2O_{(g)} \rightarrow H_2O_{(s)}$ 2) $H_2O_{(s)} \rightarrow H_2O_{(l)}$ 3) $H_2O_{(s)} \rightarrow H_2O_{(g)}$ 4) $H_2O_{(l)} \rightarrow H_2O_{(g)}$

11b) select correct representation of the sublimation of water, on the basis of the pictures A, B and C



Picture A Picture B Picture C

1) Picture B → Picture C 2) Picture A → Picture C
3) Picture A → Picture B 4) Picture C → Picture A

11c) select the correct schematic representation of the sublimation of water (molecules of water are represented by the blac kdots):

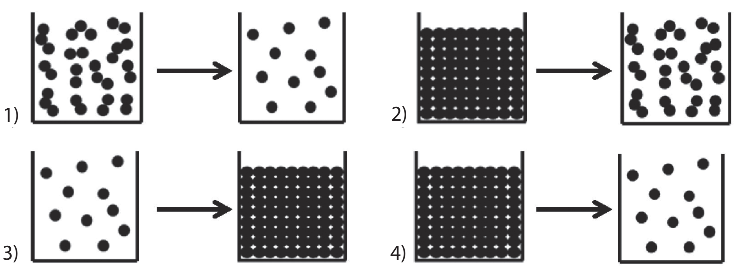
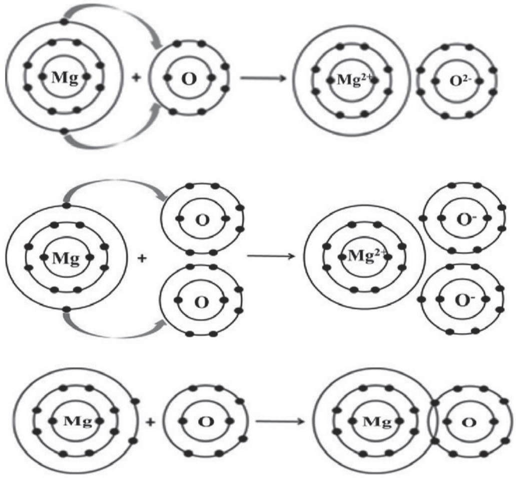


Figure 1. Full contents of Item 1
(all photograps and schemata were taken/made by the author)

12a) write chemical equation of the reaction of magnesium oxidation:

12b) select the correct schematic representation of the mechanismo of the reaction of magnesium oxidation:



1)

2)

3)

12c) select the correct picture representation of the reaction of magnesium oxidation:

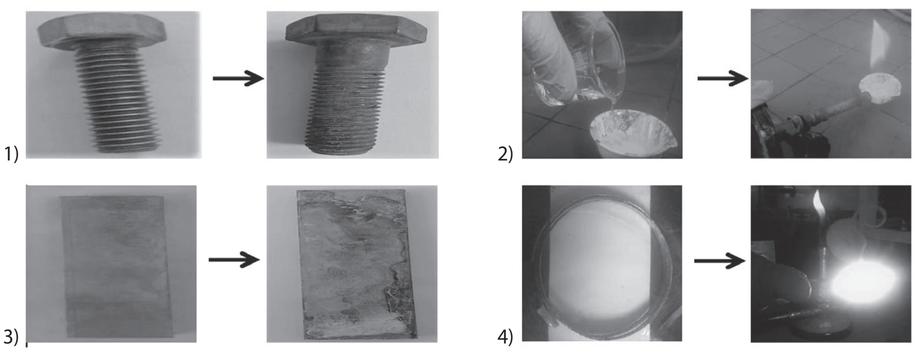


Figure 2. Full contents of Item 2
(all photograps and schemata were taken/made by the author)

Data analysis

For each of the subitems within I1 and I2, the proportion of correct answers for all three age groups of students was determined.

Normality of distribution of the 14-year-old, 16-year-old and 19-year-old students' results on the Achievement test was confirmed by the results of the Jarque-Bera test (p_{14}=.213; p_{16}=.192; p_{19}=.435), which was proven to outperform other tests of normality for sample sizes of around 100 (Frain, 2006). This enabled the use of parametric tests within further data analysis.

In order to ascertain whether each of the age groups exibits significant differences in understanding of the sublimation of water and the reaction of magnesium oxidation at the macroscopic, submicroscopic and symbolic level and whether the three age groups exhibit significant differences in the depth of understanding of the abovementioned concepts at each of the levels of chemistry knowledge, One-Way ANOVA was applied. The significance level for these analyses was .05. In instances where statistically significant differences had been found, Bonferroni's *post hoc* test was applied. The aim of these multiple pair-wise comparisons was to determine between which levels of chemistry knowledge (subitems within I1 and I2) the statistically significant differences in understanding occur for each age group, and between which age groups the statistically significant differences in the depth of understanding occur at each of the levels of chemistry knowledge. Conducting Bonferroni's correction presumed that for each of the pair-wise comparisons the significance level was kept at .05, while the *p* values were adjusted by multiplying the observed *p* value with the total number of comparisons that were carried out.

Results

Within I1, I1a referred to the sublimation of water at the symbolic level, I1b referred to this process at the macroscopic level, while I1c referred to the sublimation of water at the submicroscopic level. The proportion of correct answers (p) of the 14-year-old, 16-year-old and 19-year-old students to each of the subitems within I1 is presented in Table 1.

Table 1
The proportion of correct answers of the 14-year-old, 16-year-old and 19-year-old students on the three subitems within I1

Students' age	p_{I1a}	p_{I1b}	p_{I1c}
14	0.521	0.537	0.322
16	0.667	0.731	0.491
19	0.795	0.821	0.616

The results of the comparison of achievements of the 14-year-old, 16-year-old and 19-year-old students on each of the subitems within I1 are presented in Table 2.

Table 2
The comparison of achievements of the 14-year-old, 16-year-old and 19-year-old students on each of the subitems within I1

Subitem	dF	*F*	*p*
I1a	2, 338	10.216*	<.001
I1b	2, 338	12.338*	<.001
I1c	2, 338	10.730*	<.001

Note. *Difference in the achievement is statistically significant at the level of $p<.05$.

The results presented in Table 2 indicate that there are statistically significant differences in the achievements of the three age groups of students on I1a, I1b and I1c. In order to determine between which age groups the statistically significant differences in the achievement occur on each of the subitems, pair-wise comparisons have been conducted. The results of these comparisons are presented in Table 3.

Table 3
The results of pair-wise comparisons of achievement of the 14-year-old, 16-year-old and 19-year-old students on each of the subitems within I1

Subitem	Compared age groups	Difference in the proportion of correct answers	*p*
I1a	16 : 14	0.146*	.048
I1a	19 : 14	0.274*	<.001
I1a	19 : 16	0.128	.164
I1b	16 : 14	0.194*	.003
I1b	19 : 14	0.284*	<.001
I1b	19 : 16	0.090	.411
I1c	16 : 14	0.169*	.028
I1c	19 : 14	0.294*	<.001
I1c	19 : 16	0.125	.170

Note. *Difference in the achievements of the two age groups is statistically significant at the level of $p<.05$.

As can be seen in Table 3, the 19-year-old students significantly outperformed the 14-year-old students on all of the subitems within I1. Furthermore, the 16-year-old students also significantly outperformed the 14-year-old students on I1a, I1b and I1c. At the same time, there were no statistically significant differences in the achievement of the 19-year-old and 16-year-old students, on any of the subitems within I1.

The results of the comparison of achievements of each age group of students on I1a, I1b and I1c are presented in Table 4.

Table 4
The comparison of achievements of each age group of students on the three subitems within I1

Students' age	dF	*F*	*p*
14	2, 360	7.183*	.001
16	2, 321	7.451*	.001
19	2, 333	7.595*	.001

Note. *Difference in the achievements is statistically significant at the level *of* $p<.05$.

The results presented in Table 4 indicate that there are statistically significant differences in the achievements of each age group on the three subitems within I1. In order to determine between which subitems/levels of chemistry knowledge the statistically significant differences in achievements occur for each age group, pair-wise comparisons have been conducted. The results of these comparisons are presented in Table 5.

Table 5
The results of pair-wise comparisons of achievements of the 14-year-old, 16-year-old and 19-year-old students on the three subitems within I1

Students' age	Compared subitems	Difference in the proportion of correct answers	*p*
14	I1a : I1b	-0.016	2.389
14	I1a : I1c	0.199*	.005
14	I1b : I1c	0.215*	.002
16	I1a : I1b	-0.064	.948
16	I1a : I1c	0.176*	.020
16	I1b : I1c	0.240*	.001
19	I1a : I1b	-0.026	1.912
19	I1a : I1c	0.179*	.006
19	I1b : I1c	0.205*	.001

Note. *Difference in the achievements on the two subitems is statistically significant at the level of $p<.05$.

As can be seen in Table 5, all three age groups of students showed significantly better understanding of the sublimation of water at the macroscopic (I1b), in comparison to the submicroscopic level (I1c). The results further indicate that all three age groups had significantly better understanding of the sublimation of water at the symbolic (I1a), in comparison to the submicroscopic level (I1c). On the other hand, none of the three age groups showed a significant difference in understanding of the sublimation of water at the macroscopic (I1b) and symbolic level (I1a).

Within I2, I2a referred to the reaction of magnesium oxidation at the symbolic level, I2b referred to this reaction at the submicroscopic level, while I2c referred to the reaction of magnesium oxidation at the macroscopic level. The proportion of correct answers (p) of the three age groups of students on each of the subitems within I2 is presented in Table 6.

Table 6
The proportion of correct answers of the 14-year-old, 16-year-old and 19-year-old students on the three subitems within I2

Students' age	p_{I2a}	p_{I2b}	p_{I2c}
14	0.479	0.322	0.612
16	0.667	0.491	0.778
19	0.777	0.607	0.839

The results of the comparison of achievement of the 14-year-old, 16-year-old and 19-year-old students on each of the subitems within I2 are presented in Table 7.

Table 7
The comparison of achievements of the 14-year-old, 16-year-old and 19-year-old students on each of the subitems within I2

Subitem	dF	*F*	*p*
I2a	2, 338	12.146*	<.001
I2b	2, 338	10.106*	<.001
I2c	2, 338	8.795*	<.001

Note. *Difference in the achievement is statistically significant at the level of $p<.05$.

The results presented in Table 7 indicate that there are statistically significant differences in the achievements of the three age groups of students on I2a, I2b and I2c. In order to determine between which age groups the statistically significant differences in the achievements occur on each of the subitems, pair-wise comparisons have been conducted. The results of these comparisons are presented in Table 8.

Table 8

The results of pair-wise comparisons of achievements of the 14-year-old, 16-year-old and 19-year-old students on each of the subitems within I2

Subitem	Compared age groups	Difference in the proportion of correct answers	*p*
I2a	16 : 14	0.188*	.008
I2a	19 : 14	0.298*	<.001
I2a	19 : 16	0.110	.243
I2b	16 : 14	0.169*	.028
I2b	19 : 14	0.285*	<.001
I2b	19 : 16	0.116	.232
I2c	16 : 14	0.166*	.031
I2c	19 : 14	0.227*	<.001
I2c	19 : 16	0.061	.869

Note. *Difference in the achievements of the two age groups is statistically significant at the level of $p<.05$.

As can be seen in Table 8, the 19-year-old students significantly outperformed the 14-year-old students on all of the subitems within I2. Furthermore, the 16-year-old students also significantly outperformed the 14-year-old students on I2a, I2b and I2c. At the same time, there were no statistically significant differences in the achievements of the 19-year-old and 16-year-old students, on any of the subitems within I2.

The results of the comparison of achievements of each age group of students on I2a, I2b and I2c are presented in Table 9.

Table 9

The comparison of achievements of each age group of students on the three subitems within I2

Students' age	dF	*F*	*p*
14	2, 360	10.669*	<.001
16	2, 321	10.425*	<.001
19	2, 333	8.787*	<.001

Note. *Difference in the achievements is statistically significant at the level of $p<.05$.

The results presented in Table 9 indicate that there are statistically significant differences in the achievements of each age group on the three subitems within I2. In order to determine between which subitems/levels of chemistry knowledge the statistically significant differences in achievements occur for each age group, pair-wise comparisons have been conducted. The results of these comparisons are presented in Table 10.

Table 10
The results of pair-wise comparisons of achievements of the 14-year-old, 16-year-old and 19-year-old students on the three subitems within I1

Students' age	Compared subitems	Difference in the proportion of correct answers	*p*
14	I2a : I2b	0.157*	.038
14	I2a : I2c	-0.133	.106
14	I2b : I2c	-0.290*	<.001
16	I2a : I2b	0.176*	.018
16	I2a : I2c	-0.111	.242
16	I2b : I2c	-0.287*	<.001
19	I2a : I2b	0.170*	.010
19	I2a : I2c	-0.062	.829
19	I2b : I2c	-0.232*	<.001

Note. *Difference in the achievements on the two subitems is statistically significant at the level of $p<.05$.

As can be seen in Table 10, all three age groups showed significantly better understanding of the reaction of magnesium oxidation at the macroscopic (I2c), in comparison to the submicroscopic level (I2b). The results further indicate that all three age groups had significantly better understanding of the reaction of magnesium oxidation at the symbolic (I2a), in comparison to the submicroscopic level (I2b). On the other hand, none of the three age groups showed a significant difference in the understanding of the reaction of magnesium oxidation at the macroscopic (I2c) and symbolic level (I2a).

Discussion and implications

The results of this study indicate that the 16-year-old and 19-year-old students have significantly better understanding of the sublimation of water and the reaction of magnesium oxidation at the macroscopic, submicroscopic and symbolic level, in comparison to the 14-year-old students. Such results are not contradictory to the assumption made within the model of the expanding triangle that students' understanding of chemical concepts, at all three levels of chemistry knowledge, increases with the age of students/number of years of Chemistry learning. However, no statistically significant differences in the understanding of the sublimation of water and the reaction of magnesium oxidation were found for the 16-year-old and 19-year-old students, at neither of the three levels of chemistry knowledge. This finding could, perhaps, be related to the 19-year-old students' ability to apply abstract thinking in regard to these particular concepts. More specifically, given their age, it is expected that all studens who formed the research sample reached the stage of formal operations in their cognitive development. This stage is marked by the development of abstract thinking, which enables students to understand abstract principles which have no physical reference, use symbols in order to represent and understand abstract concepts, and manipulate multiple variables simultaneously. Students are also able to make generalizations about the things that they have observed and use these concrete experiences in order to form hypotheses and consider concepts (Berk, 2007). Therefore, abstract thinking is a prerequisite for the development of conceptual understanding at all three levels of chemistry knowledge and dealing with all three levels simultaneously. It is important to note that the ability to think abstractly is greatly improved through practice. Furthermore, abstract thinking is domain specific, which is why practice of its application in one field of study will only promote abstract thinking in that particular domain (Slavin, 2006). After the reintroduction to the sublimation of water and the reaction of magnesium oxidation within the study of physical and chemical changes in the first year of grammar school (at the age of 16), the 19-year-old students also encountered these concepts in the second year of grammar school, within the study of inorganic chemistry. However, their next two years of Chemistry learning were devoted solely to the study of organic chemistry and biochemistry. Since under these conditions they had little opportunity to practice the application of abstract thinking in terms of physical and chemical changes of inorganic compounds, this could be the reason why they were not able to demonstrate significantly better understanding of the sublimation of water and the reaction of magnesium oxidation at each of the three levels of chemistry knowledge, in comparison to the 16-year-old students.

Research results further indicate that the 14-year-old, 16-year-old and 19-year-old students have significantly better understanding of the sublimation of water and the reaction of magnesium oxidation at the macroscopic and symbolic, in comparison to the submicroscopic level, while differences in understanding at the macroscopic and symbolic level are negligible. The results concerning the reaction of magnesium oxidation confirm the previous findings that students' understanding of chemical reactions tends to be limited to the macroscopic and symbolic level (Chandrasegaran et al., 2007; Jaber & BouJaoude, 2011) and that their ability to represent chemical reactions at the symbolic level is no guarantee of understanding at the submicroscopic level (Kern et al., 2010; Krajcik, 1991). The results concerning the understanding of the sublimation of water also confirm the previous finding that students tend to have better understanding of the process of sublimation at the macroscopic, in comparison to the submicroscopic level (Rahayu & Kita, 2010). In view of the fact that the 14-year-old, 16-year-old and 19-year-old students experienced the greatest difficulties with understanding of the sublimation of water and the reaction of magnesium oxidation at the submicroscopic level, it should be noted that teaching about physical and chemical changes at this level, to all three age groups, mostly revolved around static representations in Chemistry textbooks. On the other hand, Ardac and Akaygun (2005) found that students' understanding of these concepts at the particulate level could be improved through the use of dynamic computer representations. The abovementioned results also show that the 14-year-old students, who were just completing their first year of Chemistry learning, were able to deal with the sublimation of water and the reaction of magnesium oxidation at the macroscopic level more or at least as successfully as at the other two levels of chemistry knowledge. Therefore, the results of this study are not contrary to the assumption made within the rising iceberg model, that Chemistry teaching to novice students should start from the macroscopic level. However, they also imply that, when it comes to teaching these students about physical and chemical changes teachers could consider an early introduction of the symbolic level, alongside the macroscopic level. Introduction of another level, alongside the macroscopic level, has already been considered for teaching other branches of chemistry to novice students. For example, Johnstone (2000) recommended that introductory organic chemistry teaching should "begin with the macro and can afford to take in some submicro" (p.12). Given that the 16-year-old and 19-year-old students also showed significantly better understanding of the sublimation of water and the reaction of magnesium oxidation at the macroscopic and symbolic, in comparison to the submicroscopic level, research results further imply that each subsequent reintroduction of these concepts to older students should not differ from teaching to novice students, in terms of the sequence of levels in which the knowledge is presented.

Conclusion

This study explored how students' conceptual understanding of physical and chemical changes at the macroscopic, submicroscopic and symbolic level develops over time. Within the study, 14-year-old, 16-year-old and 19-year-old students completed the test that checked their understanding of the sublimation of water as an example of a physical change and the reaction of magnesium oxidation as an example of a chemical change, at each of the levels. Thus obtained results were used in order to validate the previously proposed models of the expanding triangle and rising iceberg.

The study found that the 16-year-old and 19-year-old students have significantly better understanding of the sublimation of water and the reaction of magnesium oxidation in comparison to the 14-year-old students, at all three levels of chemistry knowledge. These findings support the proposition made within the expanding triangle model that students' understanding of chemistry concepts, at each of the three levels, increases with the age of students/number of years of chemistry learning. However, this study also found that, when it comes to the 16-year-old and 19-year-old students, differences in understanding of the abovementioned concepts at the macroscopic, submicroscopic and symbolic level are negligible. This could have been caused by the fact that the study dealt with physical and chemical changes of inorganic compounds, while the 19-year-old students, within their two previous years of Chemistry learning, dealt only with organic and biochemical compounds. Given that abstract thinking, which is a prerequisite for the development of conceptual understanding at all three levels of chemistry knowledge is domain specific, this could have impeded the development of the 19-year-old students' understanding of the sublimation of water and the reaction of magnesium oxidation at the macroscopic, submicroscopic and symbolic level. Therefore, it can be concluded that the way in which the Chemistry curriculum is composed has a profound impact on the development of students' conceptual understanding, at all three levels of chemistry knowledge.

The study also found that the 14-year-old, 16-year-old and 19-year old students have significantly better understanding of the sublimation of water and the reaction of magnesium oxidation at the macroscopic and symbolic, in comparison to the submicroscopic level, while differences in understanding at the macroscopic and symbolic level, for each age group, are negligible. Although such findings are not contrary to the assumption made within the rising iceberg model that Chemistry teaching to novice students should start from the macroscopic level, they do indicate that an early introduction of this content at the symbolic level, alongside the macroscopic level, could also be beneficial. Furthermore, each subsequent reintroduction of these concepts to older students should not differ from teaching them to novice students, in terms of the sequence of levels in which the knowledge is presented.

It is important to note that all research findings should be interpreted with caution, in view of certain limitations. First, the number of students from all three age groups is relatively small. Furthermore, the study was cross-sectional, whereas it might have been better if it had been longitudinal, so that only one population of students was followed over time. Therefore, within future research, the implementation of the longitudinal approach should be favored. Also, in order to draw general conclusions about the development of students' understanding of these concepts, more examples of physical and chemical changes should be considered. Finally, future research could examine whether the recommendations made within this study in regard to the teaching about physical and chemical changes have a positive impact on the development of students' understanding of these concepts, at all three levels of chemistry knowledge.

Acknowledgement

This research was financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Contract number: 451-03-68/2020-14/200288).

References

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction*, *16*(3), 183-198. https://doi.org/10.1016/j.learninstruc.2006.03.001

Ardac, D., & Akaygun, S. (2005). Using static and dynamic visuals to represent chemical change at molecular level. *International Journal of Science Education*, *27*(11), 1269-1298. https://doi.org/10.1080/09500690500102284

Baddeley, A. (1990). *Human memory: Theory and practice*. Lawrence Erlbaum Associates.

Berk, L. E. (2007). *Development through the lifespan*. Allyn and Bacon.

Briggs, H., & Holding, B. (1986). *Aspects of secondary students' understanding of elementary ideas in Chemistry: Summary report*. University of Leeds.

Chandrasegaran, A. L., Treagust, D. F., & Mocerino, M. (2007). The development of a two-tier multiple-choice diagnostic instrument for evaluating secondary school students' ability to describe and explain chemical reactions using multiple levels of representation. *Chemistry Education Research and Practice*, *8*(3), 293-307. https://doi.org/10.1039/B7RP90006F

Childs, P. E., & Sheehan, M. (2009). What's difficult about chemistry? An Irish perspective. *Chemistry Education Research and Practice*, *10*(3), 204-218. https://doi.org/10.1039/ B914499B

Chittleborough, G. (2014). The development of theoretical frameworks for understanding the learning of chemistry. In I. Devetak, & S. A. Glažar (Eds.), *Learning with Understanding in the Chemistry Classroom* (pp. 25-40). Springer Science+Business Media B.V. https://doi.org/10.1007/978-94-007-4366-3_2

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika*, *16*(3), 297-334. https://doi.org/10.1007/bf02310555

Frain, J. C. (2006). *Small sample power of tests of normality when the alternative is an α-stable distribution.* Trinity College.

Jaber, L. Z., & BouJaoude, S. (2012). A macro-micro-symbolic teaching to promote relational understanding of chemical reactions. *International Journal of Science Education*, *34*(7), 973-998. https://doi.org/10.1080/09500693.2011.569959

Johnson, P. (1998a). Children's understanding of changes of state involving the gas state, Part 1: Boiling water and the particle theory. *International Journal of Science Education*, *20*(5), 567-583. https://doi.org/10.1080/0950069980200505

Johnson, P. (1998b). Children's understanding of changes of state involving the gas state, Part 2: Evaporation and condensation below boiling point. *International Journal of Science Education*, *20*(6), 695-709. https://doi.org/10.1080/0950069980200607

Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*, *7*(2), 75-83. https://doi.org/10.1111/j.1365-2729.1991.tb00230.x

Johnstone, A. H. (2000). Teaching of chemistry – logical or psychological?. *Chemistry Education Research and Practice, 1*(1), 9-15. https://doi.org/10.1039/A9RP90001B

Kern, A. L., Wood, N. B., Roehrig, G. H., & Nyachwaya, J. (2010). A qualitative report of the ways high school chemistry students attempt to represent a chemical reaction at the atomic/molecular level. *Chemistry Education Research and Practice*, *11*(3), 165-172. https://doi.org/10.1039/C005465H

Krajcik, J. (1991). Developing students' understanding of chemical concepts. In S. M. Glynn, R. H. Yeany, & B. K. Britton (Eds.), *The Psychology of Learning Science* (pp. 117-147). Lawrence Erlbaum Associates Inc.

Miller, G. A. (1968). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *101*(2), 343-352. https://doi.org/10.1037/0033-295X.101.2.343

Nuić, I., & Glažar, S. (2015). Application of web-based learning material for teaching states of matter in 8th grade primary school chemistry - a pilot study results. *Bulletin of the Chemists and Technologists of Bosnia and Herzegovina*, *45*, 43-50.

Peterson, R., Treagust, D. F., & Garnett, P. (1989). Development and application of a diagnostic instrument to evaluate grade-11 and -12 students' concepts of covalent bonding and structure following a course of instruction. *Journal of Research in Science Teaching*, *26*(4), 301-314. https://doi.org/10.1002/tea.3660260404

Rahayu, S., & Kita, M. (2010). An analysis of Indonesian and Japanese students' understanding of macroscopic and submicroscopic levels of representing matter and its changes. *International Journal of Science and Mathematics Education*, *8*(4), 667-688. https://doi.org/10.1007/s10763-009-9180-0

Schollum, B. (1981). *Chemical change: A working paper of the Learning in Science*. University of Waikato.

Slavin, E. R. (2006). *Educational psychology: Theory and practice*. Pearson Education Inc.

Sunyono, S., & Sudjarwo, S. (2018). Mental models of atomic structure concepts of 11th grade chemistry students. *Asia-Pacific Forum of Science Learning and Teaching*, *19*(1), Article 9.

Taber, K. S. (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. https://doi.org/10.1039/C3RP00012E

Treagust, D. F., Chittleborough, G., & Mamiala, T. L. (2003). The role of submicroscopic and symbolic representations in chemical explanations. *International Journal of Science Education*, *25*(11), 1353-1368. https://doi.org/10.1080/0950069032000070306

Katarina Putica
Innovative Centre of the Faculty of Chemistry
University of Belgrade
Studentski trg 12-16, 11158 Belgrade, Serbia
puticakatarina@gmail.com

Razvoj konceptualnoga razumijevanja fizikalnih i kemijskih promjena na makroskopskoj, podmikroskopskoj i simboličkoj razini – međugeneracijsko istraživanje

Sažetak

Kako bi se objasnio način na koji se tijekom vremena razvija proces razumijevanja kemijskih pojmova na makroskopskoj, podmikroskopskoj i simboličkoj razini, predlažu se dva modela: model ekspanzijskoga trokuta i model rastućega ledenjaka. S ciljem provjere valjanosti ovih dvaju modela, u ovom je istraživanju ispitano mijenja li se u značajnoj mjeri razina razumijevanja pojmova vezanih uz fizikalne i kemijske promjene na svakoj od navedenih razina s dobi učenika, pokazuju li odabrane dobne skupine značajne razlike u razumijevanju na navedenim razinama te razlikuju li se rezultati dobiveni za ove dobne skupine. U sklopu istraživanja, 121 učenik u dobi od 14 godina, 108 učenika u dobi od 16 godina te 112 učenika u dobi od 19 godina riješili su test kojim se provjeravalo njihovo razumijevanje ranije spomenutih pojmova, na sve tri razine. Učenici u dobi od 16 i 19 godina ostvarili su značajno bolje rezultate od učenika u dobi od 14 godina, na svakoj razini, dok su sve dobne skupine pokazale značajno bolje razumijevanje fizikalnih i kemijskih promjena na makroskopskoj i simboličkoj u usporedbi s podmikroskopskom razinom. Zaključak je da, iako su predloženi modeli općenito gledajući valjani, nastavne metode koje se primjenjuju i struktura kurikula za Kemiju imaju veliki utjecaj na razvoj konceptualnoga razumijevanja kod učenika, na sve tri razine kemijskoga znanja.

Ključne riječi: *model ekspanzijskoga trokuta; model rastućega ledenjaka; oksidacija magnezija; sublimacija vode.*

Uvod

Učenicima je Kemija često apstraktan i konceptualno težak nastavni predmet (Childes i Sheehan, 2009), što se može povezati s njezinom intrinzičnom naravi, tj. činjenicom da kemijsko znanje postoji na tri različite razine (Johnstone, 2000). Makroskopska razina obuhvaća ono što se može vidjeti, dotaknuti i pomirisati; podmikroskopska razina obuhvaća atome, molekule, ione i strukture, dok simbolička razina obuhvaća različite vizualne prikaze simbola, formula, jednadžbi, molarnosti, matematičkih manipulacija i grafova. Kako nijedna od ove tri razine nije superiorna u odnosu na ostale razine, nego se one međusobno dopunjavaju, važan aspekt pružanja razumljivih objašnjenja učenicima jest voditi računa o tome da razumiju ulogu svake razine i da ih međusobno povezuju (Treagust, Chittleborough i Mamiala, 2003). Kako bi se taj cilj ostvario, od učenika se često očekuje da razmišljaju na višestrukim razinama dok uče o novim kemijskim pojmovima. Johnstone (1991) je ovaj proces ilustrirao pomoću trokuta čije je vrhove označio kao makro, podmikro i simbolički. Objasnio je da umjesto fokusiranja na jedan vrh ili na jednu stranicu trokuta, nastava Kemije uglavnom se odvija unutar trokuta, a učenici se moraju istovremeno snalaziti na sve tri razine. Istraživanja su pokazala da, kada se nastava Kemije odvija na ovakav način, učenici mogu razvijati konceptualno razumijevanje kemijskih pojava (Ainsworth, 2006). Imajući to na umu, Johnstone (2000) je, međutim, doveo u pitanje logiku istovremenoga uvođenja svih triju razina u radu s učenicima koji tek počinju učiti kemiju. Smatra da situacija u kojoj učenici moraju obraditi toliku količinu novih informacija jednostavno nadilazi kapacitet radne memorije ljudskoga mozga, što ograničava broj „blokova" novih informacija kojima se može manipulirati u bilo koje vrijeme (Miller, 1968). Iako radna memorija ne stvara nove „utore" za pohranu informacija kako učenici sazrijevaju, poznavanje pojmova omogućava svakom tom „utoru" pohranjivanje većega broja informacija (Baddeley, 1990). Zbog toga dubinsko razumijevanje bilo kojega kemijskoga pojma, na sve tri razine kemijskoga znanja, postaje vremenom sve veće (Taber, 2013). S obzirom na to da je makroskopska razina najpoznatija učenicima koji počinju učiti kemiju, Johnstone (2000) smatra da početna nastava Kemije treba početi upravo na ovoj razini, a zatim bi se postupno trebale uvesti i ostale dvije razine.

U skladu s ovim stavovima, Chittleborough (2014) je predložio dva modela kako bi objasnio postupni proces razvoja razumijevanja kemijskih pojmova kod učenika na tri razine kemijskoga znanja. Oba modela povezana su s Johnstoneovim trokutom. Kako su kurikuli za Kemiju spiralne strukture, nakon uvoda u ključne kemijske pojmove učenici im se još nekoliko puta vraćaju tijekom daljnjega školovanja. Na taj način njihovo razumijevanje na svakom vrhu trokuta raste kako se dalje odvija proces učenja. Zbog toga se trokut širi te je zato prvi model nazvan modelom ekspanzijskoga trokuta. Drugi predloženi model nazvan je modelom rastućega ledenjaka. U njemu se naglašava slijed upotrebe triju razina u nastavi Kemije te njegov utjecaj na konceptualno razumijevanje kod učenika. Model se temelji na trokutu u kojemu je makroskopska razina označena na gornjem vrhu, dok su podmikroskopska i simbolička razina označena na donja dva vrha. Vodoravna linija, koja predstavlja morsku razinu, nacrtana je preko trokuta. Područje iznad te linije je osjenčano te predstavlja rastuće razumijevanje kod učenika. Kako makroskopska razina najviše odgovara učenicima koji počinju učiti kemiju, gornji vrh trokuta uvijek je uključen u nastavni proces, dok se podmikroskopska i simbolička razina uvode samo onda kada je to potrebno. S vremenom se veći dio ovih razina može otkrivati učenicima te se na taj način njihovo dubinsko razumijevanje povećava. Analogno tomu, vodoravna linija spušta se prema dolje, a osjenčano se područje povećava.

Očito je da ova dva modela mogu predstavljati vrijedan izvor informacija o razvoju konceptualnoga razumijevanja kod učenika, na sve tri razine kemijskoga znanja. Međutim, valjanost ni jednoga od tih modela do sada još nije potvrđena rezultatima kvantitativnih istraživanja.

Pregled literature o učeničkom razumijevanju fizikalnih i kemijskih promjena na makroskopskoj, podmikroskopskoj i simboličkoj razini

S obzirom na to da fizikalne i kemijske promjene predstavljaju ključne kemijske pojmove, u mnogobrojnim istraživanjima ispitivano je učeničko razumijevanje tih pojmova, na sve tri razine kemijskoga znanja.

Kada se radi o promjenama agregatnih stanja tvari, kao primjera fizikalnih promjena, Rahayo i Kita (2010) ispitali su koliko temeljito učenici u dobi između 15 i 18 godina razumiju promjene iz krutoga u tekuće, krutoga u plinovito i tekućega u plinovito stanje. Temeljito razumijevanje definirali su kao razumijevanje promjena i na makroskopskoj i na podmikroskopskoj razini. Najveće poteškoće uočili su u vezi s promjenom iz krutoga u plinovito stanje jer je manje od 25 % učenika iz svih odabranih dobnih skupina pokazalo temeljito razumijevanje procesa sublimacije naftalena. Istovremeno svi su učenici pokazali bolje razumijevanje triju vrsta promjena na makroskopskoj, nego na podmikroskopskoj razini. Poteškoće koje su učenici imali u razumijevanju promjena agregatnih stanja tvari također su u nekim istraživanjima uočene i na podmikroskopskoj razini. Na primjer, uočeno je da učenici u dobi između 12 i 13 godina imaju poteškoće u razumijevanju promjena iz tekućega u plinovito stanje na ovoj razini (Nuić i Glažar, 2015). Johnson (1998a, 1998b) je došao do saznanja da učenici u dobi između 11 i 14 godina imaju veće poteškoće u razumijevanju procesa isparavanja i kondenzacije, nego u razumijevanju procesa topljenja i zamrzavanja na čestičnoj razini. Stoga je zaključio da promjene koje uključuju plinovito stanje učenicima zadaju više problema.

Kada se radi o kemijskim promjenama, Jaber i BouJaoude (2011) zaključili su da je razumijevanje kemijskih reakcija kod učenika u dobi od 15 godina obično ograničeno na makroskopsku i simboličku razinu, dok su podmikroskopsku razinu često pomiješali s makroskopskom razinom, u smislu konstrukta i jezika. Tendenciju petnaestogodišnjaka da predviđaju kakva će makroskopska svojstva tvari imati na podmikroskopskoj razini kada obrađuju kemijske reakcije potvrdili su Chandrasegaran, Treagust i Mocerino (2007). Učenici su, između ostaloga, izrazili uvjerenje da su crveno-smeđi atomi bakra nastali u reakciji istiskivanja između cinka i bakrova (II) sulfata. Nadalje, sposobnost prikazivanja kemijske reakcije na simboličkoj razini nije se pokazala garancijom da će učenici jednako tako biti sposobni prikazati istu reakciju na podmikroskopskoj razini. Na primjer, utvrđeno je da je od 65,3 % srednjoškolaca koji su mogli točno prikazati izgaranje metana na simboličkoj razini, samo njih 31,1 % moglo je nacrtati prikaz ove reakcije koja pokazauju odgovarajuće razumijevanje na čestičnoj razini (Kern, Wood, Roehrig i Nyachwaya, 2010). Zaključeno je da, iako se čini da su mnogi učenici ovladali simboličkim vještinama potrebnima za točno prikazivanje kemijskih reakcija, oni to često čine tako što kemijskim jednadžbama pristupaju kao matematičkim zadatcima u kojima brojevi s obje strane jednadžbe moraju biti jednaki (Krajcik, 1991).

U ranijim je istraživanjima također uočeno da učenici imaju poteškoće u razlikovanju fizikalnih i kemijskih promjena i na čestičnoj, i na makroskopskoj razini. Na primjer, više od 65 % učenika u dobi između 16 i 17 godina bilo je uvjereno da podmikroskopski dijagram koji prikazuje dijeljenje molekule dvoatomskoga elementa na dva atoma toga elementa predstavlja fizikalnu promjenu, uspoređujući proces s komadom papira koji se može poderati na dva dijela (Sunyono i Sudjarwo, 2018). Kada se radi o makroskopskoj razini, uočeno je da oko 70 % učenika u dobi od 14 godina i više od 50 % učenika u dobi od 16 godina smatra da razrjeđivanje koncentriranoga voćnog soka vodom predstavlja kemijsku promjenu, dok 48 % učenika u dobi od 14 godina i 55 % učenika u dobi od 16 godina smatra da otapanje šećera u vodi predstavlja kemijsku promjenu (Schollum, 1981). To je dovelo do zaključka da učenici često stvaraju pogrešne zaključke da je fizikalna promjena, u stvari, kemijska promjena, na temelju vizualnih znakova, tj. „supstanca mijenja boju, masu i stanje pa se može činiti očitim da je u pitanju kemijska promjena" (Briggs i Holding, 1986, str. 63).

Ciljevi istraživanja

Kako se može vidjeti u pregledu literature, nije provedeno ni jedno istraživanje koje je ispitivalo kako se dubinsko razumijevanje fizikalnih i kemijskih promjena na svakoj od tri razine kemijskoga znanja mijenja s dobi učenika ili godinama učenja Kemije kao nastavnoga predmeta. Nadalje, ni jedno provedeno istraživanje nije se bavilo učeničkim razumijevanjem fizikalnih promjena na simboličkoj razini. U prethodna dva primjera ispitano je pokazuju li učenici određene dobne skupine razlike u dubini razumijevanja kemijskih promjena na makroskopskoj, podmikroskopskoj i simboličkoj razini, no nijedno ranije provedeno istraživanje o fizikalnim ili kemijskim promjenama nije ispitalo postoje li takve razlike kada se radi o drugim dobnim skupinama učenika ili razlikuju li se rezultati učenika u različitim dobnim skupinama. Stoga je potrebno provesti istraživanje čiji bi se rezultati mogli koristiti za procjenu i provjeru ranije predloženih modela ekspanzijskoga trokuta i rastućega ledenjaka. Na taj se način mogu dobiti važne informacije o načinima na koje se učeničko konceptualno razumijevanje fizikalnih i kemijskih promjena na trima razinama kemijskoga znanja razvija tijekom vremena. Stoga je prvi cilj ovoga istraživanja usporediti dubinu konceptualnoga razumijevanja fizikalnih i kemijskih promjena na sve tri razine kemijskoga znanja, za tri odabrane dobne skupine učenika (učenika u dobi od 14 , 16 i 19 godina). Drugi je cilj bio odrediti pokazuje li svaka od odabranih dobnih skupina učenika razlike u razumijevanju fizikalnih i kemijskih promjena na makroskopskoj, podmikroskopskoj i simboličkoj razini te razlikuju li se po razinama rezultati dobiveni za tri dobne skupine.

Metodologija

Uzorak istraživanja

Uzorak u ovom istraživanju sastojao se od 121 učenika osnovne škole u dobi od 14 godina (srednja dob = 169 mjeseci), 108 gimnazijalaca u dobi od 16 godina (srednja dob = 193 mjeseca) te 112 gimnazijalaca u dobi od 19 godina (srednja dob = 228 mjeseci) u Srbiji. Svi su učenici dobrovoljno sudjelovali u istraživanju. U vrijeme kada je ono provedeno, učenici u dobi od 14 godina bili su na kraju sedmoga razreda osnovne škole te na kraju prve godine učenja kemije. Učenici u dobi od 16 godina bili su na kraju prvoga razreda gimnazije i treće godine učenja kemije, dok su devetnaestogodišnjaci bili na kraju četvrtoga (završnoga) razreda gimnazije i šeste godine učenja kemije. Svi gimnazijalci pohađali su prirodoslovni smjer.

Potrebno je istaknuti da je kurikul za Kemiju u Srbiji spiralnoga karaktera te da se Kemija poučava kao zaseban predmet u osnovnoj školi i u gimnaziji. Učenici se prvo upoznaju s pojmovima fizikalnih i kemijskih promjena u sedmom razredu osnovne škole, a ponovno ih obrađuju u prvom razredu gimnazije. U drugom razredu gimnazije proučavaju anorgansku kemiju, dok u trećem i četvrtom razredu proučavaju organsku kemiju i biokemiju. Detaljnom razradom svih tipova organskih, biokemijskih i anorganskih spojeva učenici mogu steći opsežno znanje o fizikalnim i kemijskim svojstvima i promjenama tih spojeva.

Prikupljanje podataka

Kvantitativni podatci prikupljeni su pomoću Testa postignuća, koji je izrađen upravo za potrebe ovoga istraživanja. Test se sastojao od dviju glavnih tvrdnji, a učenici su imali 45 minuta vremena za rješavanje testa. Tvrdnjom 1 (I1) provjeravalo se koliko učenici razumiju proces sublimacije vode, kao primjer fizikalne promjene, dok se Tvrdnjom 2 (I2) provjeravalo njihovo razumijevanje reakcije oksidacije magnezija, kao primjer kemijske promjene. Obje tvrdnje sadržavale su tri podtvrdnje (po jednu podtvrdnju za svaku razinu kemijskoga znanja).

Indeksi težine za šest podtvrdnji u sklopu Testa postignuća varirali su u rasponu između 0,32 i 0,61 kod učenika u dobi od 14 godina, između 0,49 i 0,75 kod učenika u dobi od 16 godina te između 0,61 i 0,79 kod učenika u dobi od 19 godina. Indeksi diskriminacije bili su u rasponu između 0,35 i 0,68 kod učenika u dobi od 14 godina, između 0,42 i 0,66 kod učenika u dobi od 16 godina te između 0,39 i 0,71 kod učenika u dobi od 19 godina. Kako su sve vrijednosti indeksa težine i indeksa diskriminacije bile unutar prihvatljivoga raspona između 0,3 i 0,8 (Peterson, Treagus i Garnett, 1989), zaključeno je da su razina težine i diskriminacijska snaga Testa postignuća zadovoljavajuće. Nadalje, Cronbachov alfa koeficijent korišten je kao mjera testa pouzdanosti, a njegova je vrijednost bila 0,76 za test koji su riješili učenici u dobi od 14 godina, 0,74 za test koji su riješili učenici u dobi od 16 godina te 0,78 za test koji su riješili učenici u dobi od 19 godina. S obzirom na to da su sve vrijednosti bile iznad najniže prihvatljive vrijednosti od 0,70 (Cronbach, 1951), zaključeno je da je test pouzdan.

Cjeloviti sadržaj dviju tvrdnji u Testu postignuća prikazan je na Slici 1 i na Slici 2.

Slika 1.

Slika 2 .

Analiza podataka

Za svaku podtvrdnju u I1 I I2 određen je broj točnih odgovora, za sve tri dobne skupine učenika.

Normalnost distribucije rezultata koje su učenici u dobi od 14, 16 i 19 godina ostvarili na Testu postignuća potvrđena je pomoću Jarque-Bera testa (p_{14} = 0,213; p_{16} = 0,192; p_{19} = 0,435), za koji se pokazalo da je učinkovitiji od ostalih testova normalnosti na uzorcima od stotinjak ispitanika (Frain, 2006). To je omogućilo primjenu parametrijskih testova u daljnjoj analizi podataka.

Kako bi se utvrdilo pokazuje li svaka dobna skupina ispitanika značajne razlike u razumijevanju procesa sublimacije vode i reakcije oksidacije magnezija na makroskopskoj, podmikroskopskoj i simboličkoj razini te pokazuju li tri dobne skupine ispitanika značajne razlike u dubini razumijevanja gore spomenutih pojmova na svakoj razini kemijskoga znanja, primijenjena je jednosmjerna analiza varijance ANOVA. Vrijednost razina značajnosti u ovim analizama iznosila je 0,05. U primjerima u kojima su uočene statistički značajne razlike, primijenjen je Bonferronijev *post hoc* test. Cilj ovih višestrukih komparacija parova bio je odrediti između kojih se razina kemijskoga znanja (podtvrdnje unutar tvrdnji I1 i I2) javljaju statistički značajne razlike u razumijevanju u svakoj dobnoj skupini te između kojih se dobnih skupina javljaju statistički značajne razlike u dubini razumijevanja na svakoj razini kemijskoga znanja. Provedba Bonferronijeve korekcije podrazumijevala je da se vrijednost razine značajnosti zadrži na 0,05 za svaku komparaciju para, dok su se *p* vrijednosti prilagođavale tako što se promatrana *p* vrijednost pomnožila ukupnim brojem provedenih komparacija.

Rezultati

U sklopu tvrdnje I1, podtvrdnja I1a odnosila se na sublimaciju vode na simboličkoj razini, I1b na taj proces na makroskopskoj razini, dok se podtvrdnja I1c odnosila na sublimaciju vode na podmikroskopskoj razini. Broj točnih odgovora (p) učenika u dobi od 14, 16 i 19 godina za svaku od podtvrdnji unutar tvrdnje I1 prikazan je u Tablici 1.

Tablica 1.

Rezultati komparacije postignuća skupina učenika u dobi od 14, 16 i 19 godina na svakoj od podtvrdnji unutar tvrdnje I1 prikazani su u Tablici 2.

Tablica 2.

Rezultati prikazani u Tablici 2 upućuju na to da postoje statistički značajne razlike u postignućima triju dobnih skupina učenika u podtvrdnjama I1a, I1b i I1c. Kako bi se odredilo između kojih dobnih skupina postoje statistički značajne razlike u postignućima za svaku podtvrdnju, provedena je komparacija parova. Rezultati komparacija prikazani su u Tablici 3.

Tablica 3.

Kako se može vidjeti u Tablici 3, učenici u dobi od 19 godina ostvarili su značajno bolje rezultate od učenika u dobi od 14 godina, u svim podtvrdnjama unutar tvrdnje I1. Nadalje, učenici u dobi od 16 godina također su ostvarili značajno bolje rezultate od učenika u dobi od 14 godina u podtvrdnjama I1a, I1b i I1c. No, nisu uočene statistički značajne razlike u postignućima učenika u dobi od 19 i 16 godina, ni za jednu podtvrdnju unutar tvrdnje I1.

Rezultati komparacije postignuća svake dobne skupine učenika u podtvrdnjama I1a, I1b i I1c prikazani su u Tablici 4.

Tablica 4.

Rezultati prikazani u Tablici 4 pokazuju da postoje statistički značajne razlike u postignućima svake dobne skupine u trima podtvrdnjama unutar tvrdnje I1. Kako bi se odredilo između kojih se podtvrdnji/razina kemijskoga znanja javljaju statistički značajne razlike u postignućima kod svake dobne skupine, provedena je komparacija parova. Rezultati komparacija prikazani su u Tablici 5.

Tablica 5.

Kako se može vidjeti u Tablici 5, sve tri dobne skupine učenika pokazale su značajno bolje razumijevanje procesa sublimacije vode na makroskopskoj razini (I1b), u usporedbi s podmikroskopskom razinom (I1c). Rezultati pokazuju da su sve tri dobne skupine imale značajno bolje razumijevanje procesa sublimacije vode na simboličkoj razini (I1a), u usporedbi s podmikroskopskom razinom (I1c). S druge strane, ni jedna od te tri dobne skupine nije pokazala značajnu razliku u razumijevanju procesa sublimacije vode na makroskopskoj (I1b) I simboličkoj (I1a) razini.

U sklopu tvrdnje I2, podtvrdnja I2a odnosila se na reakciju oksidacije magnezija na simboličkoj razini, I2b na istu reakciju na podmikroskopskoj razini, a podtvrdnja I2c na rekaciju oksidacije magnezija na makroskopskoj razini. Broj točnih odgovora (p) triju dobnih skupina učenika na svakoj od podtvrdnji unutar tvrdnje I2 prikazan je u Tablici 6.

Tablica 6.

Rezultati komparacije postignuća učenika u dobi od 14, 16 i 19 godina za svaku podtvrdnju unutar tvrdnje I2 prikazani su u Tablici 7.

Tablica 7.

Rezultati prikazani u Tablici 7 upućuju na statistički značajne razlike u postignućima triju dobnih skupina u podtvrdnjama I2a, I2b i I2c. Kako bi se odredilo između kojih se dobnih skupina javljaju statistički značajne razlike na svakoj od podtvrdnji, provedene su komparacije parova. Rezultati komparacija prikazani su u Tablici 8.

Tablica 8.

Kako se može vidjeti u Tablici 8, učenici u dobi od 19 godina ostvarili su značajno bolje rezultate od učenika u dobi od 14 godina, i to u svim podtvrdnjama unutar tvrdnje I2. Nadalje, učenici u dobi od 16 godina također su ostvarili znatno bolje rezultate od učenika u dobi od 14 godina, u podtvrdnjama I2a, I2b i I2c. Nisu uočene statistički značajne razlike u postignućima učenika u dobi od 19 i od 16 godina, ni na jednoj od podtvrdnji unutar tvrdnje I2.

Rezultati komparacije postignuća svake dobne skupine u potvrdnjama I2a, I2b i I2c prikazani su u Tablici 9.

Tablica 9.

Rezultati prikazani u Tablici 9 pokazuju da postoje statistički značajne razlike u postignućima svake dobne skupine u tri podtvrdnje unutar tvrdnje I2. Kako bi se odredilo između kojih se podtvrdnji/razina kemijskoga znanja javljaju statistički značajne razlike u postignućima, provedene su komparacije parova. Rezultati komparacija prikazani su u Tablici 10.

Tablica 10.

Kako se može vidjeti u Tablici 10, sve tri dobne skupine pokazale su značajno bolje razumijevanje reakcije oksidacije magnezija na makroskopskoj (I2c) razini, u usporedbi s podmikroskopskom razinom (I2b). Rezultati dalje pokazuju da su sve tri dobne skupine imale značajno bolje razumijevanje reakcije oksidacije magnezija na simboličkoj razini (I2a), u usporedbi s podmikroskopskom razinom (I2b). S druge strane, ni jedna od triju dobnih skupina nije pokazala značajne razlike u razumijevanju reakcije oksidacije magnezija na makroskopskoj (I2c) i simboličkoj razini (I2a).

Rasprava i implikacije

Rezultati ovoga istraživanja pokazuju da učenici u dobi od 16 i 19 godina značajno bolje razumiju proces sublimacije vode i reakciju oksidacije magnezija na makroskopskoj, podmikroskopskoj i simboličkoj razini, nego što je to slučaj kod učenika u dobi od 14 godina. Takvi rezultati odgovaraju i pretpostavci o modelu ekspanzijskoga trokuta prema kojoj se učeničko razumijevanje kemijskih pojmova na sve tri razine kemijskoga znanja povećava s dobi učenika, tj. brojem godina učenja Kemije kao nastavnoga predmeta. Međutim, nisu uočene statistički značajne razlike u razumijevanju procesa sublimacije vode i reakcije oksidacije magnezija kod učenika u dobi od 16 i 19 godina, ni na jednoj od triju razina kemijskoga znanja. Ovaj rezultat možda se može povezati sa sposobnošću devetnaestogodišnjaka da o ovim pojmovima razmišljaju apstraktno. Točnije, s obzirom na njihovu dob, očekuje se da su svi učenici koji su činili uzorak istraživanja dosegli razinu formalnih operacija kognitivnoga razvoja. Za tu je razinu karakterističan razvoj apstraktnoga mišljenja, koji učenicima pomaže razumjeti apstraktne pojmove koji nemaju fizički oblik, koristiti simbole kako bi prikazali i razumjeli apstraktne pojmove te manipulirati višestrukim varijablama istovremeno. Učenici su također sposobni izvoditi generalizacije o stvarima koje su promatrali i koristiti ta konkretna iskustva za formuliranje hipoteza i analizu pojmova (Berk, 2007). Stoga je apstraktno mišljenje preduvjet za razvoj konceptualnoga razumijevanja na sve tri razine kemijskoga znanja i za razmišljanje na sve tri razine istovremeno. Važno je istaknuti da se sposobnost apstraktnoga mišljenja uvelike poboljšava vježbom. Nadalje, apstraktno je mišljenje specifično za određenu domenu pa je to razlog zašto uvježbavanje njegove primjene u jednom području istraživanja potiče apstraktno mišljenje samo u toj određenoj domeni (Slavin, 2006). Nakon ponovljene obrade gradiva o procesu sublimacije vode i reakciji oksidacije magenzija u sklopu istraživanja o fizikalnim i kemijskim promjenama u prvom razredu gimnazije (učenici u dobi od 16 godina), učenici u dobi od 19 godina ponovno su se s istim pojmovima susreli u drugom razredu gimnazije, dok su proučavali anorgansku kemiju. Međutim, njihove sljedeće dvije godine nastave Kemije bile su rezervirane samo za proučavanje organske kemije i biokemije. Kako su pod ovim uvjetima imali malo prilika vježbati primjenu apstraktnoga mišljenja u vezi s fizikalnim i kemijskim promjenama anorganskih spojeva, to bi mogao biti razlog zašto nisu mogli pokazati znatno bolje razumijevanje procesa sublimacije vode i reakcije oksidacije magnezija na svakoj od triju razina kemijskoga znanja, u usporedbi s učenicima u dobi od 16 godina.

Rezultati istraživanja dalje pokazuju da učenici u dobi od 14, 16 i 19 godina imaju značajno bolje razumijevanje procesa sublimacije vode i reakcije oksidacije magnezija na makroskopskoj i simboličkoj razini, u usporedbi s podmikroskopskom razinom, dok su razlike u razumijevanju na makroskopskoj i simboličkoj razini zanemarive. Rezultati koji se odnose na reakciju oksidacije magnezija potvrđuju ranija saznanja da je učeničko razumijevanje kemijskih reakcija ograničeno na makroskopsku i simboličku razinu (Chandrasegaran i sur., 2007; Jaber i BouJaoude, 2011) i da njihova sposobnost prikazivanja kemijskih reakcija na simboličkoj razini ne znači da te reakcije razumiju i na podmikroskopskoj razini (Kern i sur., 2010; Krajcik, 1991). Rezultati koji se odnose na razumijevanje procesa sublimacije vode također potvrđuju ranija saznanja da učenici bolje razumiju proces sublimacije vode na makroskopskoj razini, u usporedbi s podmikroskopskom razinom (Rahayu i Kita, 2010). U skladu s činjenicom da su učenici u dobi od 14, 16 i 19 godina imali najviše poteškoća s razumijevanjem procesa sublimacije vode i reakcije oksidacije magnezija na podmikroskopskoj razini, potrebno je istaknuti da se nastavni proces u kojemu su se obrađivale fizikalne i kemijske promjene na ovoj razini kod svih triju dobnih skupina uglavnom bazirao na statičnim prikazima u udžbenicima za Kemiju. S druge strane, Ardac i Akaygun (2005) došli su do saznanja da se način na koji učenici razumiju ove pojmove na čestičnoj razini može poboljšati upotrebom dinamičnih prikaza na računalu. Ranije spomenuti rezultati također pokazuju da su učenici u dobi od 14 godina, koji su upravo završavali svoju prvu godinu učenja Kemije kao nastavnoga predmeta, mogli shvatiti proces sublimacije vode i reakciju oksidacije magnezija na makroskopskoj razini uspješnije od ili jednako uspješno kao na ostale dvije razine kemijskoga znanja. Stoga rezultati ovoga istraživanja nisu u suprotnosti s pretpostavkom o modelu rastućega ledenjaka, prema kojemu početna nastava Kemije treba krenuti od makroskopske razine. Međutim, oni također impliciraju da, kada se radi o poučavanju o fizikalnim i kemijskim promjenama kod učenika koji su početnici u kemiji, nastavnici bi trebali razmisliti o ranom uvođenju simboličke razine, uz makroskopsku razinu. Uvođenje još jedne razine uz makroskopsku razmatralo se i u nastavi ostalih grana kemije kod učenika početnika. Na primjer, Johnstone (2000) je preporučio da se početna nastava organske kemije treba „započeti s makrorazinom, uz nešto podmikro razine" (str. 12). Kako su i učenici u dobi od 16 i od 19 godina pokazali značajno bolje razumijevanje procesa sublimacije vode i reakcije oksidacije magnezija na makroskopskoj i simboličkoj razini, u usporedbi s podmikroskopskom razinom, rezultati istraživanja dalje impliciraju da se svako daljnje ponovno obrađivanje ovih pojmova sa starijim učenicima ne bi trebalo razlikovati od njihova predstavljanja učenicima početnicima, kada se govori o slijedu razina kroz koje se znanje prezentira.

Zaključak

Ovo istraživanje ispitalo je kako se učeničko konceptualno razumijevanje fizikalnih i kemijskih promjena na makroskopskoj, podmikroskopskoj i simboličkoj razini razvija tijekom vremena. U sklopu istraživanja, učenici su u dobi od 14, 16 i 19 godina riješili test kojim se provjeravalo njihovo razumijevanje procesa sublimacije vode kao primjera fizikalne promjene i reakcije oksidacije magnezija kao primjera kemijske promjene, na svakoj razini. Tako dobiveni rezultati korišteni su za provjeru valjanosti prethodno predloženih modela ekspanzijskoga trokuta i rastućega ledenjaka.

U istraživanju je utvrđeno da učenici u dobi od 16 i 19 godina znatno bolje razumiju proces sublimacije vode i reakciju oksidacije magnezija, u usporedbi s učenicima u dobi od 14 godina, i to na sve tri razine kemijskoga znanja. Ovi rezultati idu u prilog pretpostavci o ekspanzijskom trokutu prema kojoj se učeničko razumijevanje kemijskih pojmova na svakoj od triju razina poboljšava kako učenici tijekom vremena sazrijevaju i s povećanjem broja godina učenja Kemije kao nastavnoga predmeta. Međutim, u ovom istraživanju također je utvrđeno da su, kada se radi o učenicima u dobi od 16 i 19 godina, razlike u razumijevanju gore navedenih pojmova na makroskopskoj, podmikroskopskoj i simboličkoj razini zanemarive. To je možda uzrokovano činjenicom da se istraživanje bavilo fizikalnim i kemijskim promjenama anorganskih spojeva, dok su učenici u dobi od 19 godina, tijekom ranije dvije godine učenja Kemije, na nastavi obrađivali samo organske i biokemijske spojeve. S obzirom na to da je apstraktno mišljenje, koje je preduvjet za razvoj konceptualnoga razumijevanja na sve tri razine kemijskoga znanja specifično za pojedinu domenu, ono je moglo onemogućiti bolje konceptualno razumijevanje procesa sublimacije vode i reakcije oksidacije magnezija na makroskopskoj, podmikroskopskoj i simboličkoj razini kod učenika u dobi od 19 godina. Stoga se može zaključiti da struktura kurikula za Kemiju ima veliki utjecaj na način na koji učenici izgrađuju konceptualno razumijevanje na sve tri razine kemijskoga znanja.

U istraživanju je također utvrđeno da učenici u dobi od 14, 16 i 19 godina znatno bolje razumiju proces sublimacije vode i reakciju oksidacije magnezija na makroskopskoj i simboličkoj razini, u usporedbi s podmikroskopskom razinom, dok su razlike u razumijevanju na makroskopskoj i na simboličkoj razini zanemarive, i to kod svake dobne skupine. Iako takvi rezultati odgovaraju pretpostavci o modelu rastućega ledenjaka, prema kojoj bi početno učenje kemije trebalo početi od makroskopske razine, oni ipak upućuju na to da bi rano uvođenje ovakvoga sadržaja na simboličkoj, uz makroskopsku razinu, također bilo vrlo korisno. Nadalje, svako ponovno vraćanje na te pojmove kod starijih učenika ne bi se trebalo razlikovati od načina obrađivanja tih pojmova na početnoj nastavi Kemije, kada se radi o redoslijedu razina na kojima se znanje prikazuje.

Važno je istaknuti da bi se svi rezultati istraživanja trebali interpretirati vrlo oprezno, zbog određenih ograničenja. Kao prvo, broj učenika u svima trima dobnim skupinama je relativno malen. Nadalje, istraživanje je presječno, dok bi možda bilo bolje da je bilo longitudinalno jer bi se tada pratila samo jedna populacija učenika tijekom određenoga vremenskoga perioda. Stoga bi se u budućim istraživanjima prednost trebala dati longitudinalnim istraživanjima. Kako bi se omogućilo stvaranje općenitih zaključaka o načinu na koji se kod učenika razvija razumijevanje ovih pojmova, u istraživanju bi trebalo obuhvatiti veći broj fizikalnih i kemijskih promjena. Na kraju, buduća istraživanja mogla bi ispitati imaju li preporuke koje su rezultat ovoga istraživanja, a koje se odnose na način na koji se učenike na nastavi Kemije poučava o fizikalnim i kemijskim promjenama, pozitivan utjecaj na razvoj učeničkoga razumijevanja tih pojmova, na sve tri razine kemijskoga znanja.

Zahvala

Ovo istraživanje financiralo je Ministarstvo prosvjete, znanosti i tehnološkoga razvoja Republike Srbije (Broj ugovora: 451-03-68/2020-14/200288).