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УДК 37.011.33:54-047.24
DOI 10.46793/Uzdanica20.1.171P
Оригинални научни рад
Примљен: 24. фебруар 2023.
Прихваћен: 12. мај 2023.

A CROSS-AGE STUDY OF THE DEVELOPMENT OF UNDERSTANDING OF THE CONCEPT OF MATTER AT THE MACROSCOPIC AND SUB-MICROSCOPIC LEVEL[1]

Abstract: This cross-age study aimed to provide an insight into the development of students' understanding of the concept of matter, at the macroscopic and sub-microscopic level of chemistry knowledge. The research sample encompassed 121 students aged 14 years, 108 students aged 16 years and 112 students aged 19 years. All students completed the test comprised of five pictures and five schemata which depicted a monatomic/diatomic element, a compound and a homogeneous/heterogeneous mixture, at both of the levels. In this way, it was examined whether the selected age groups exhibit significant differences in understanding of elements, compounds and mixtures at the above-mentioned levels and whether the depth of understanding of these concepts at the macroscopic and sub-microscopic level significantly changes with the age of students. Research results indicate that all three age groups have a significantly better understanding of diatomic elements, compounds and heterogeneous mixtures at the macroscopic, in comparison to the sub-microscopic level and a significantly better understanding of monatomic elements and homogeneous mixtures at the sub-microscopic, in comparison to the macroscopic level. Overall, a significant improvement of understanding of the concept of matter, at each of the levels, was only observed between the ages of 14 and 16.

Keywords: cross-age study, development of understanding, elements, compounds, mixtures.

INTRODUCTION

Explanations of chemical processes are primarily based on the theoretical models of the structure of matter at the sub-microscopic level (Taber 2013: 158; Chittleborough 2014: 29; Slapničar et al. 2018: 620). This represents a considerable challenge for students who have to acknowledge the existence of particles which cannot be perceived through the senses, learn about their structure and prop-

[1] This research was financed by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, contract number: 451-03-68/2022-14/200288.

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erties and finally use all this knowledge in order to construct abstract explanations (Taber 2013: 158). Learning at the tangible and visible macroscopic level is also riddled with difficulties, which mostly arise from the fact that, instead of referring to materials which students regularly encounter in their daily lives, macroscopic chemistry deals with the abstract and unfamiliar concepts of pure substances and mixtures (Taber 2013: 159). Furthermore, during a typical chemistry lesson, students are often required to apply multilevel thinking. This means that, along with dealing with the macroscopic and sub-microscopic level at the same time, students must also present the knowledge from these two levels with appropriate symbolic representations (Johnstone 1991: 78). While multilevel thinking is necessary for the attainment of deep understanding of all chemical concepts (Chandrasegaran, Treagust, Mocerino 2007: 294; Taber 2013: 164, 166), its application in introductory chemistry teaching is debatable due to the fact that such an amount of new information inevitably surpasses the capacity of the novice students' working memory, which can only hold a limited amount of new information at the given time (Johnstone 2000: 11).

Although the working memory does not develop more slots for holding new information as the students mature, familiarity with conceptual material allows each slot to hold a larger amount of interrelated data (Baddeley 1997: 49–51). Given that the macroscopic level is the most familiar to novice students, it was proposed that introductory chemistry teaching should start from this level (Johnstone 2000: 12). Additionally, as most chemistry curricula are spiral, students will have a chance to revisit a certain concept several times during their elementary and secondary school chemistry education. Therefore, it was proposed that the depth of understanding of the concept in question, at all levels of chemistry knowledge, increases as the learning proceeds (Chittleborough 2014: 34–35). This proposition, however, has never been validated through quantitative research, while there is only a limited amount of evidence that supports the notion that chemistry teaching to novice students should start from the macroscopic level (Tsaparlis 2009: 43–44). Furthermore, there are no recommendations on whether the same teaching approach should also be applied when it comes to the older students.

Since matter represents a core chemical concept, several studies explored students' understanding of it at the macroscopic and sub-microscopic level. For example, through interviews with the 15-year-old students, it was concluded that most of them understand the macroscopic nature of an element (Briggs, Holding 1986: 50–51). On the other hand, it was established that the students who selected to study chemistry past the age of 16 struggle to understand the differences between elements and compounds, at the sub-microscopic level (Kind 2004: 23). It was also determined that the students aged 15–18 have a satisfactory understanding of homogeneous mixtures at the macroscopic level (Rahayu, Kita 2010: 684), while the 19-year-old students do not experience great difficulties when it comes to distinguishing between homogeneous and heterogeneous mixtures, at this level

(Sanger 2000: 764). In terms of the sub-microscopic level, the research that used different colored dots to represent atoms of different elements within a diagram of a compound, found that nearly half of the 15-year-old students believed that this diagram depicts a mixture (Briggs, Holding 1986: 48). Furthermore, it was reported that the 14-year-old students experience considerable difficulties when it comes to distinguishing between a diatomic element and a compound at this level (Slapničar et al. 2018: 626), while students aged 17 years struggle with discerning between homogeneous and heterogeneous mixtures (Toth, Kiss 2006: 120, 123).

As can be seen, previous research primarily explored the understanding of pure substances (elements and compounds) and mixtures of a particular age group of students, at either the macroscopic or sub-microscopic level. Consequently, the results of these studies do not provide enough information about the ways in which students' understanding of the concept of matter, at each of the levels, develops over time. Conducting a research that deals with this topic would be beneficial for several reasons. For example, in this way it could be established whether the depth of understanding of elements, compounds and mixtures at the two levels rises at a constant rate as the learning progresses, or the rise in understanding occurs only within a specific time frame. If such a time frame exists, this would represent a crucial period in students' chemistry education for the development of understanding of the above-mentioned concepts. Furthermore, by comparing the depth of understanding of pure substances and mixtures at the two levels for novice students, it would be possible to ascertain whether they actually are able to deal with these concepts more successively at the macroscopic level and whether the recommendation referring to introductory chemistry teaching that starts from this level is justified. Additionally, by doing the same comparison for older students, it would be possible to determine whether the identical approach to teaching about pure substances and mixtures should also be applied in their instance, or the approach that requires the application of multilevel thinking would be better advised.

RESEARCH AIMS

The first aim of this research was to ascertain whether each of the three selected age groups of students (the 14-, 16- and 19-year-old students) exhibits a significant difference in the depth of understanding of pure substances and mixtures at the macroscopic and sub-microscopic level and whether the findings for the above-mentioned age groups differ among them. The second aim was to compare the depth of understanding of pure substances and mixtures of the three age groups at the macroscopic and sub-microscopic level and, thus, determine whether the depth of understanding of these concepts, at each of the levels, significantly changes with the age of students.

RESEARCH SAMPLE

The research sample encompassed 121 seventh-grade elementary school students aged 14 years, 108 first-year grammar school students aged 16 years and 112 fourth-year grammar school students aged 19 years and it was formed from one class of the 14-year-old students from four elementary schools and one class of the 16- and 19-year-old students from four grammar schools in Serbia. All grammar school students were enrolled in the natural sciences stream of study. At the time when the research was conducted the 14-year-old students were just completing their first year of chemistry learning, the 16-year-olds were at the end of their third year of chemistry learning, while the 19-year-old students were about to complete their sixth year of education in the field of chemistry.

ETHICAL CONSIDERATIONS, DESIGN AND PROCEDURE

Following the review of the research aims and the contents of the research instrument, the permission to conduct this study was granted by the director of each participating school. The students from the classes that were randomly selected to form the research sample were explained that the study presupposed completing of a test about pure substances and mixtures, the results of which would be used to explore students' understanding of the concept of matter. Data confidentiality was guaranteed and it was explained that the test would be completed on a strictly voluntary basis. The students were also told that taking the test would not earn them any benefits, while the decision not to take the test would not cause any negative consequences. Furthermore, they would be able to withdraw from the research whenever they choose, without any repercussions. Based on this information, all students from the selected classes decided to take the test, upon which they were given one chemistry lesson period, lasting 45 minutes, to complete it.

RESEARCH INSTRUMENT

The research data were collected by means of the test composed by the authors of this study, which encompassed a single item (I1). I1 consisted of 10 sub-items, five of which contained a picture, while the other five contained a schema. Beside each picture and schema, the students were expected to write whether it depicts a monatomic/diatomic element, a compound, or a homogeneous/heterogeneous mixture. Within the schemata which depicted a compound and the two types of mixtures at the sub-microscopic level, atoms of different elements were represented by dots of different colors. When it comes to the pictures, four of them represented objects which are familiar to students from their daily lives (graphite core of a pencil, yogurt in a glass, table salt and a piece of cake). The fifth picture presented the process of iodine sublimation, which is ordinarily demonstrated to students within the elaboration of the changes of the states of matter, at the beginning of the seventh grade of elementary school.

In order to check the readability, reliability and the difficulty level of the test, pilot study was conducted. 26 students aged 14, 31 students aged 16 and 29 students aged 19 who participated in the pilot study came from one elementary and one grammar school in Belgrade, none of which took part in the main study. Upon completing the test, the students from all three age groups confirmed that they could easily distinguish between dots of different colors within the schemata and that this type of sub-microscopic representations was familiar to them. They also confirmed that the objects, as well as the process of iodine sublimation, presented within the pictures in the test were easily recognizable. The proportion of correct answers of the three age groups on all ten sub-items in the test was within the acceptable range between 0,30 and 0,80 (the values ranged from 0,31 to 0,65 for the 14-year-old students, from 0,45 to 0,68 for the 16-year-old students and from 0,52 to 0,76 for the 19-year-old students), indicating that the difficulty level of the test was appropriate. At the same time, Cronbach's alpha value for the test completed by the 14-year-old students was 0,77, the value for the test completed by the 16-year-old students was 0,73, while for the test completed by the 19-year-old students Cronbach's alpha had the value of 0,81. Since all three values were above the lowest acceptable value of 0,70, it was concluded that the test is reliable. However, based on the feedback provided by the students who took part in the pilot test, all pictures and schemata were enlarged, and this revised form of the test was used in the main study. The Cronbach's alpha values for the test completed by the 14-, 16- and 19-year old students in the main study were 0,79, 0,75 and 0,82, respectively.

DATA ANALYSIS

The students' answers to each of the sub-items within I1 were given the score of *1* if correct, while incorrect answers scored *0*. To determine whether the distribution of the 14-, 16- and 19-year-old students' scores on the test was normal, the values of the skewness and kurtosis were calculated. Since all the values were within the acceptable range between -1 and +1 (14-year-old students: skewness = +0,09, kurtosis = -0,11; 16-year-old students: skewness = +0,23, kurtosis = +0,09; 19-year-old students: skewness = +0,47, kurtosis = -0,36), it was concluded that the data collected for all three age groups are normally distributed. This enabled the use of parametric tests within further data analysis.

To establish whether the 14-, 16- and 19-year-old students exhibit significant differences in understanding of pure substances and mixtures at the macroscopic and sub-microscopic level, paired *t*-test was applied.

To ascertain whether the depth of understanding of elements, compounds and mixtures at the macroscopic and sub-microscopic level significantly changes as the students mature, one-way analysis of variance (one-way ANOVA) was implemented. When it comes to the concepts for which such changes have been detected, Tukey's HSD test was applied in order to specify between which age groups the significant differences in the depth of understanding occur.

RESULTS AND DISSCUSION

The mean scores (*M*) of the 14-, 16- and 19-year-old students on each of the sub-items within I1 are presented in Table 1 (mean score of 1 indicates that the sub-item was answered correctly by all students from the given age group).

Table 1. The mean scores of the three age groups of students on each of the sub-items within I1

Students' age	*M*I1a	*M*I1b	*M*I1c	*M*I1d	*M*I1e	*M*I1f	*M*I1g	*M*I1h	*M*I1i	*M*I1j
14	0,372	0,446	0,322	0,314	0,306	0,496	0,595	0,471	0,479	0,430
16	0,546	0,454	0,407	0,611	0,472	0,759	0,630	0,722	0,602	0,611
19	0,625	0,589	0,545	0,644	0,571	0,786	0,759	0,768	0,777	0,723

The *t*-test values calculated in order to compare the 14-, 16- and 19-year-old students' understanding of monatomic elements at the macroscopic (I1a) and sub-microscopic (I1h) level are presented in Table 2.

Table 2. The comparison of mean scores of each age group on sub-items referring to monatomic elements at the macroscopic (I1a) and sub-microscopic (I1h) level

Students' age	*M*I1h – *M*I1a	df	*t*	*p*
14	0,099	120	2,153[a]	0,0333
16	0,176	107	3,596[b]	0,0005
19	0,143	111	2,173[a]	0,0319

[a] Significant at the level of $p < 0,05$; [b] Significant at the level of $p < 0,01$

The results presented in Table 2 indicate that the students from all three age groups showed a significantly better understanding of the concept of a monatomic element at the sub-microscopic in comparison to the macroscopic level, which opposes the findings of previous research (Kind 2004: 23).

The results of the comparison of the 14-, 16- and 19-year-old students' understanding of diatomic elements at the macroscopic (I1j) and sub-microscopic (I1e) level are presented in Table 3.

Table 3. The comparison of mean scores of each age group on sub-items referring to diatomic elements at the macroscopic (I1j) and sub-microscopic (I1e) level

Students' age	*M*I1j – *M*I1e	df	*t*	*p*
14	0,124	120	2,274[a]	0,0247
16	0,139	107	2,052[a]	0,0426
19	0,152	111	2,097[a]	0,0383

[a] Significant at the level of $p < 0,05$

The calculated *t*-test values indicate that the students from all three age groups were significantly more successful when it came to identifying a diatomic element at the macroscopic, in comparison to the sub-microscopic level.

The *t*-test values calculated in order to compare the understanding of compounds at the macroscopic (I1f) and sub-microscopic (I1d) level for each age group of students are presented in Table 4.

Table 4. The comparison of mean scores of each age group on sub-items referring to compounds at the macroscopic (I1f) and sub-microscopic (I1d) level

Students' age	*M*I1f – *M*I1d	df	*t*	*p*
14	0,182	120	3,381[b]	0,0010
16	0,148	107	2,530[a]	0,0129
19	0,142	111	3,271[b]	0,0014

[a] Significant at the level of $p < 0,05$; [b] Significant at the level of $p < 0,01$

As can be seen in Table 4, the students from all three age groups showed a significantly better understanding of the concept of a compound at the macroscopic, in comparison to the sub-microscopic level.

The results of the comparison of the 14-, 16- and 19-year-old students' understanding of homogeneous mixtures at the macroscopic (I1c) and sub-microscopic (I1i) level are presented in Table 5.

Table 5. The comparison of mean scores of each age group on sub-items referring to homogeneous mixtures at the macroscopic (I1c) and sub-microscopic (I1i) level

Students' age	*M*I1i – *M*I1c	df	*t*	*p*
14	0,157	120	2,484[a]	0,0144
16	0,195	107	2,415[a]	0,0174
19	0,232	111	3,996[b]	<0,0005

[a] Significant at the level of $p < 0,05$; [b] Significant at the level of $p < 0,01$

The calculated *t*-test values indicate that the students from all three age groups were significantly more successful when it came to identifying homogeneous mixtures at the sub-microscopic in comparison to the macroscopic level, which opposes the findings of all previous research (Toth, Kiss 2006: 120, 123; Rahayu, Kita 2010: 684).

The *t*-test values calculated in order to compare the 14-, 16- and 19-year-old students' understanding of heterogeneous mixtures at the macroscopic (I1g) and sub-microscopic (I1b) level are presented in Table 6.

Table 6. The comparison of mean scores of each age group on sub-items referring to heterogeneous mixtures at the macroscopic (I1g) and sub-microscopic (I1b) level

Students' age	*M*I1g – *M*I1b	df	*t*	*p*
14	0,149	120	3,105[a]	0,0023
16	0,176	107	3,596[a]	<0,0005
19	0,170	111	2,681[a]	0,0085

[a] Significant at the level of $p < 0,01$

As can be seen in Table 6, the students from all three age groups showed a significantly better understanding of heterogeneous mixtures at the macroscopic, in comparison to the sub-microscopic level.

Finally, the results of the comparison of the 14-, 16- and 19-year-old students' understanding of the concepts depicted within each of the sub-items in I1 are presented in Table 7.

Table 7. The comparison of mean scores of the 14-, 16- and 19-year-old students on each of the sub-items within I1

Sub-item	dF	*F*	*p*
I1a	2, 338	8,173[b]	<0,0005
I1b	2, 338	2,959	0,0532
I1c	2, 338	6,126[b]	0,0024
I1d	2, 338	20,962[b]	<0,0005
I1e	2, 338	8,901[b]	<0,0005
I1f	2, 338	18,954[b]	<0,0005
I1g	2, 338	3,854[a]	0,0221
I1h	2, 338	14,107[b]	<0,0005
I1i	2, 338	11,588[b]	<0,0005
I1j	2, 338	11,150[b]	<0,0005

[a] Significant at the level of $p < 0,05$; [b] Significant at the level of $p < 0,01$

The results of one-way ANOVA indicate that the three age groups exhibit significant differences in understanding of the concepts presented within all of the sub-items of I1 except I1b, which depicts a heterogeneous mixture at the sub-microscopic level. The lack of any improvement in understanding of this concept with the age of students could potentially be related to the fact that, after the initial introduction to heterogeneous mixtures in the seventh grade of elementary school, students could have occasionally encountered these mixtures during laboratory work (the macroscopic level), but they had practically no opportunity to acquire further knowledge about them at the sub-microscopic level, as their chemistry education progressed.

When it comes to the sub-items for which the significant changes have been detected, pairwise comparisons were conducted to specify between which age groups the significant differences in understanding occur. The instances in which the statistically significant differences have been detected, are presented in Table 8.

Table 8. The instances in which the statistically significant differences in the mean scores of the compared age groups have been detected, for each sub-item in I1

Sub-item	Compared age groups	dF	Q	*p*
I1a	16 : 14	1, 227	3,799[a]	0,0207
I1a	19 : 14	1, 231	5,567[b]	<0,0005
I1c	16 : 14	1, 227	3,601[a]	0,0398
I1c	19 : 14	1, 231	4,920[b]	0,0016
I1d	16 : 14	1, 227	5,314[b]	<0,0005
I1d	19 : 14	1, 231	6,372[b]	<0,0005
I1e	16 : 14	1, 227	3,654[a]	0,0324
I1e	19 : 14	1, 231	5,888[b]	<0,0005
I1f	16 : 14	1, 227	5,280[b]	<0,0005
I1f	19 : 14	1, 231	6,333[b]	<0,0005
I1g	16 : 14	1, 227	3,592[a]	0,0295
I1g	19 : 14	1, 231	3,757[a]	0,0284
I1h	16 : 14	1, 227	5,822[b]	<0,0005
I1h	19 : 14	1, 231	6,946[b]	<0,0005
I1i	16 : 14	1, 227	3,881[b]	0,0175
I1i	19 : 14	1, 231	6,788[a]	<0,0005
I1j	16 : 14	1, 227	4,040[a]	0,0126
I1j	19 : 14	1, 231	6,600[b]	<0,0005

[a] Significant at the level of $p < 0,05$; [b] Significant at the level of $p < 0,01$

As can be seen in Table 8, the 16- and 19-year old students significantly outperformed the 14-year-old students, on all of the analyzed sub-items. On the other hand, no significant differences between the 16- and 19-year-old students have been found, on any of these sub-items.

CONCLUSION

The results of this research indicate that, overall, the depth of students' understanding of the concept of matter significantly increases between the ages of 14 and 16, after which no further changes have been observed. Therefore, teachers should be aware that the first three years of chemistry learning could be crucial for the development of students' understanding of this concept.

The research results further show that the 14-, 16- and 19-year old students have a significantly better understanding of diatomic elements, compounds and heterogeneous mixtures at the macroscopic, in comparison to the sub-microscopic level. These findings indicate that the novice 14-year-old students can deal with the above-mentioned concepts more successfully at the macroscopic level and, thus, do not stand against the previously made recommendation that introductory chemistry teaching should start from this level. Furthermore, as the results of the 16- and 19-year-old students do not differ from the results of the 14-year-olds, it can be concluded that each subsequent reintroduction of these concepts to the older students should be done in the same manner.

On the other hand, it was also established that students from all three age groups have a significantly better understanding of monatomic elements and homogeneous mixtures at the sub-microscopic in comparison to the macroscopic level, which opposes the results of all previous research (Sanger 2000: 764; Kind 2004: 23; Toth, Kiss 2006: 120, 123; Rahayu, Kita 2010: 684). Under such circumstances, there is no strong evidence to suggest that teaching about these concepts, to either novice or older students, should start from the sub-microscopic level. Previous research, however, acknowledged that there are certain instances in which introducing another level of chemistry knowledge to novice students, alongside the macroscopic level, could be considered (Johnstone 2000: 12). Given that this research established that all three age groups of students do not find dealing with monatomic elements and homogeneous mixtures at the sub-microscopic level to be overly challenging, such an approach to teaching about these concepts could be implemented at both the introductory and more advanced levels of chemistry education.

The most important limitations of this research refer to the relatively small number of students from each age group and the fact that the research was cross-sectional. Future research should consider the application of the longitudinal approach, so that only one population of students is followed over time. Furthermore, the instruments used within future research should encompass more examples of pure substances and mixtures at the macroscopic level, as well as different types of sub-microscopic representations, such as those that depict the tridimensional structure of matter at the particulate level.

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МЕЂУГЕНЕРАЦИЈСКА СТУДИЈА О РАЗВОЈУ РАЗУМЕВАЊА ПОЈМА МАТЕРИЈЕ НА МАКРОСКОПСКОМ И СУБМИКРОСКОПСКОМ НИВОУ

Резиме: Циљ ове међугенерацијске студије био је да пружи увид у развој ученичког разумевања појма материје на макроскопском и субмикроскопском нивоу хемијских знања. Узорак истраживања обухватио је 121 ученика узраста 14 година, 108 ученика узраста 16 година и 112 ученика узраста 19 година. Сви ученици су попунили тест који се састојао из пет слика и пет шема у оквиру којих су били представљени појмови једноатомни/двоатомни елемент, једињење и хомогена/хетерогена смеша, на оба поменута нивоа. На овај начин, проверено је да ли одабране старосне групе показују значајне разлике у разумевању елемената, једињења и смеша на наведеним нивоима и да ли се степен разумевања ових појмова на макроскопском и субмикроскопском нивоу значајно мења са узрастом ученика. Резултати истраживања указују да све три старосне групе поседују статистички значајно боље разумевање двоатомних елемената, једињења и хетерогених смеша на макроскопском у односу на субмикроскопски ниво и статистички значајно боље разумевање једноатомних елемената и хомогених смеша на субмикроскопском у односу на макроскопски ниво. Генерално гледано, статистички значајно унапређење разумевања појма материје на сваком од нивоа уочено је само између 14. и 16. године.

Кључне речи: међугенерацијска студија, развој разумевања, елементи, једињења, смеше.