Chemical Education

SUBMICROSCOPIC REPRESENTATIONS AS A TOOL FOR EVALUATING STUDENTS' CHEMICAL CONCEPTIONS

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Received 13-02-2004

Abstract

The purpose of the research was to establish how successful the secondary school students who have chosen chemistry as part of their Matura exam and the first year university students are when working with basic chemical concepts concerning solutions, acids and bases as well as equilibria based on submicrorepresentations. In solving such tasks, the secondary school students with chemistry as part of their Matura exam achieved better results because in their preparation for the exam they worked with chemical concepts by linking three levels of chemical concepts (macro, submicro and symbolic level). This way of learning and teaching chemistry is rarely practised in our secondary schools. In order to reach higher cognitive levels, we would recommend that the three levels of understanding chemical concepts be linked to a greater extent.

Key words: submicroscopic representations, chemical concepts, evaluation, Matura exam.

Introduction

The complexity of chemistry teaching and learning in which observations are made on the macroscopic level (sensory information derived from a chemical process), and the explanations and theories which students are expected to understand depend on the atomic and molecular level (in terms of particles), which are represented symbolically (translated into symbols or formulas), is based on the complexity of chemistry itself.[1,2] This fact is forcing researchers to focus primarily on converting the traditional instructor-oriented model to a student-oriented model.[3] The absence of logical reasoning skills can make chemical problem solving impossible, but even if logic is present students can show many different signs of misunderstanding.[4,5]

For sufficient understanding of science phenomena, teachers and students must be able to achieve and demonstrate the transfers between the phenomenon, its submicroscopic world and symbolic representations.[6-8] Many chemistry courses concentrate only on the symbolic level of chemical education, neglecting the other two.[9] Because of this, students think that chemistry is just a science of symbols of elements, formulae of compounds and chemical equations, but they do not understand its particulate nature nor do they picture the dynamical processes.[10]

Some authors emphasize that submicrorepresentations (static or dynamic models of particles, representing a phenomenon) are useful for a proper understanding of concepts before applying them in solving mathematical problems.[11-13] Many of the new chemistry textbooks try to visualise the chemical processes with submicrorepresentations, and also some teachers include visual presentations at a submicroscopic level in teaching, learning and evaluating students' chemical and biological concepts. To support this idea, Vosniadou and Brewer have suggested the use of analogues and physical models to facilitate the reconstruction of existing schema in the long-term memory.[14] The two-dimensional drawings and three-dimensional models used to teach about the submicroscopic world of matter might be considered to be analogues of actual atoms and molecules.[2] Using analogues has a motivational effect on the students, although these methods have certain limitations in creating conceptual change.[2,15] Duit suggested that, in order for an analogue to be effective, it must be familiar to the students and it must be in a domain in which students do not have any misconceptions and have developed hypothetical and deductive reasoning.[2,15,16]

It has been reported that secondary school students had a better understanding of the particle nature of matter as a result of using models representing physical changes, than those who used conventional texts.[2,17] One step forward is to use submicrorepresentations by computer and other video technology to animate reactions and to demonstrate particle behaviour during the physical or chemical change.[1,18]

All this raises the question of whether submicroscopic representations are understandable for students and whether they help them to understand chemical processes at the submicroscopic level, which is the foundation for proper chemical knowledge and might eliminate many chemical misconceptions. The purpose of the research was to determine the ability of secondary school and first year university students' within basic chemical principles in solution, acid-base and equilibrium chemistry using submicrorepresentations.

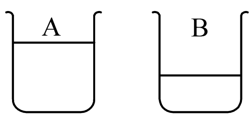
Method

Research data were collected from 350 secondary school students (average age of 18), who chose chemistry as part of their Matura exam (an exam at the end of secondary school, that all students have to pass, before entering the university), and 339 first year university students (average age of 18) enrolled in the university programme: Primary School Teacher and Teachers of Mathematics, Biology, Physics, Technical Studies and Home Economics. Both groups of students who participated in the study were the same average age, because the Matura exam was conducted at the end of secondary school, in the same year that the students went to university. University students were tested in October, i.e. at the beginning of their first semester, so that university studies could not have influenced their results. Only 6.4% of them had chemistry as a Matura exam. The students had to solve four tasks: (1) to present different concentrations of aqueous solutions by drawing the number of solvent particles; (2) to determine the base strength of anions from three submicrorepresentations regarding aqueous solutions of different sodium salts; (3) to present reaction equilibrium changes when reaction conditions were altered, and (4) to determine the equilibrium equation from the drawing and determine the type of energetic change during the reaction.

Task 1:

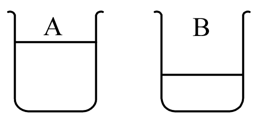
The aqueous solution of the same substance is in beakers A and B. Solution A has twice the volume of solution B. Complete the pictures with solvent particles to show that:[19]

a) solution A is more concentrated than solution B.



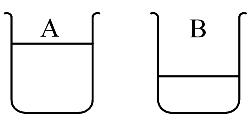
○ - the solvent particle

b) the two solutions have the same concentration.



○ - the solvent particle

c) the concentration of solution A is 1/3 the concentration of solution B.



○ - the solvent particle

Task analysis:

Illustration of the solution concentration with solvent particles (drawing schema). In separate parts of the task the concentration of the solution is altered.

a) *Constants:* equal shape and volume of the beaker, solution of the same substance.

Variables: volume of the solution in beaker B equals half the volume of the solution in beaker A; concentration of the solution in beaker A is greater than the concentration of the solution in beaker B.

b) *Constants:* equal shape and volume of the beaker, solution of the same substance; equal concentration of the solutions.

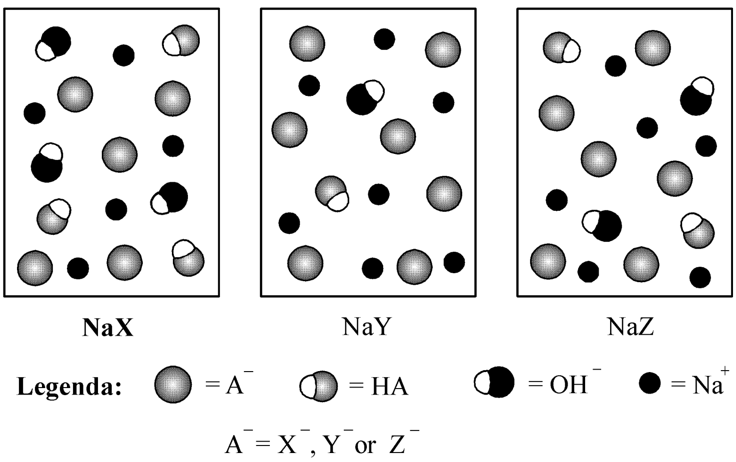
Variables: volume of the solution in beaker B equals half the volume of the solution in beaker A.

c) *Constants:* equal shape and volume of the beaker, solution of the same substance

Variables: volume of the solution in beaker B equals half the volume of the solution in beaker A; concentration of the solution in beaker A equals 1/3 of the concentration of the solution in beaker B.

Task 2:

The following pictures represent solutions of three salts NaA ($A^- = X^-$, Y^-, or Z^-); water molecules have been omitted for clarity:[20]



a) Arrange the anions X^-, Y^- and Z^- in order of increasing base strength. ____________

b) Why does each box contain the same number of HA molecules and OH^- anions?

____

Task analysis:

Reaction of salt ions with water molecules (reading of schema).

basic properties of salt anions (reading of schema);

reaction of salt anions with water molecules.

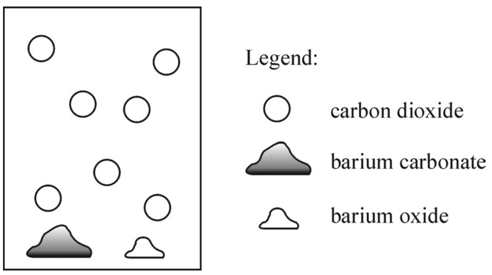
Constants: the same salt cation, in individual schema an equal number of HA particles and OH^- particles.

Variables: a different base strength of salt anions, a different number of particles (OH^-, HA) in the schema as a result of the reaction of salt anions with water molecules.

Task 3:

The products of thermal decomposition of barium carbonate are barium oxide and carbon dioxide. This reaction is reversible.[20]

a) Write a balanced equation for this reaction. In the equation denote the aggregate state of reactants and products.
Chemical Equation: ______________________________



The following picture represents an equilibrium mixture of solid barium carbonate, solid barium oxide and gaseous carbon dioxide obtained as a result of the endothermic decomposition of barium carbonate.

b) Draw a picture that represents the equilibrium mixture after addition of four more carbon dioxide molecules.

c) Draw a picture that represents the equilibrium mixture at a higher temperature.

Task analysis:

Equilibrium reactions, impact on the state of equilibrium (drawing of schema).

a) writing a balanced equation, reactants and products given;

b) determining the state of equilibrium when concentration of the substance is altered;

c) determining the state of equilibrium when temperature is altered.

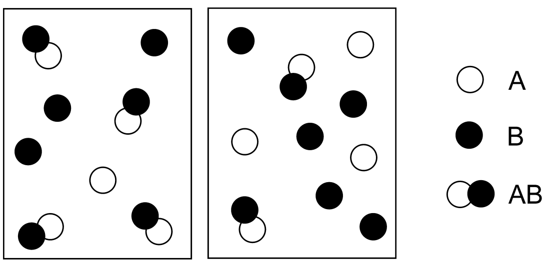
Constants: reactants and products.

Variables: different amount of reactants and products.

Task 4:

The following pictures represent the equilibrium mixture of gases at 325 and 350 K.[20]

a) Write a balanced chemical equation for the reaction that occurs on rising temperature.



T=325 K T=350 K

Chemical Equation:

____

b) Is the reaction endothermic or exothermic. Explain using Le Chatelier's principle.

____

c) If the volume of the container is increased, will the number of A atoms increase, decrease or remain the same?

increase decrease remain the same

Explain.

____

____

Task analysis:

Equilibrium reactions, impact on the state of equilibrium (reading of schema).

a) writing a balanced chemical equation (reading of schema);

b) establishing whether the reaction is endothermic or exothermic (reading of schema);

c) assessing an impact of the changed volume of container on state of equilibrium (reading of schema).

Constants: reactants and products.

Variables: different amount of reactants and products.

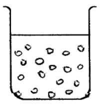
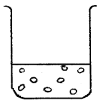
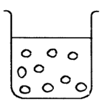
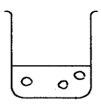
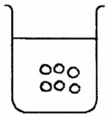
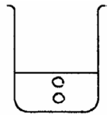
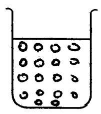
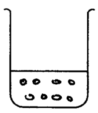
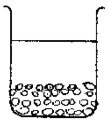
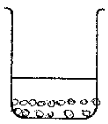
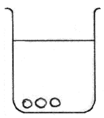
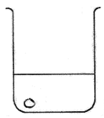
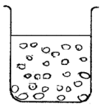
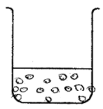
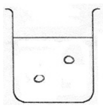
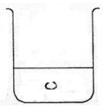
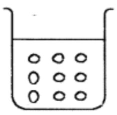
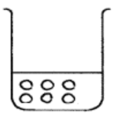
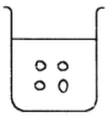
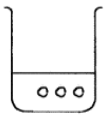
Results and discussion

Task 1:

The first task, as a whole, was correctly solved by 70.0% of secondary school students and 38.3% of university students. Altogether, 8.9% of secondary school students more than university students (77.6% of secondary school students and 68.7% of university students) correctly drew the proper number of solvent particles to illustrate the required concentration of the solution in relation to the volume of the solution in beaker A and B in part a) of the task; 16.2% more of the group of secondary school students than their university counterparts (72.3% of secondary school students and only 56.1% of university students) correctly solved part b) of the task. But students from both groups had more problems with part c) of the task, where 46.2% of the secondary school students and 41.1% of university students correctly solved the task, showing the proper concentration of the solutions involving a different volume and 1/3 of the concentration compared to the other beaker.

From the results in parts b) and c) it can be determined that some students do not have developed proportional reasoning and do not understand the particulate nature of the solutions and are not able to present graphically the arrangement of particles of the solvent in the solution (Table 1). They either drew the particles so that they were not randomly arranged in the solution (15.0% of secondary school students; 18.2% of university students) (Table 1, Figure 2), or they drew a solution in which the arrangement of the particles represented the solvent as a precipitate, at the bottom of the beaker (23.0% of secondary school students; 27.1% of university students) (Table 1, Figure 3). Some students drew the correct arrangement of the particles of the solvent, but their number was incorrect (5.0% of secondary school students; 7.3% of university students) (Table 1, Figure 4), while others made both mistakes (incorrect number and arrangement of particles) (6.3% of secondary school students; 11.2% of university students) (Table 1, Figure 5).

Table 1. Some submicroscopic representations by the secondary school students and the university students.

1a task	SS students A	SS students B	U students A	U students B
I. Appropriate number of particles, appropriate arrangement.				
Figure 1. Solution A is more concentrated than solution B. The number of particles represents the correct answer and the submicrorepresentation of the solution.				
II. Appropriate number of particles, inappropriate arrangement.				
Figure 2. Solution A is more concentrated than solution B. The number of particles is correct, but they are drawn organized in a solution.				
Figure 3. Solution A is more concentrated than solution B. The number of particles represents the correct answer, but they are drawn at the bottom of the beaker - not as a solution.				
III. Inappropriate number of particles, appropriate arrangement.				
Figure 4. Solution A is less concentrated or has the same concentration as solution B. The number of particles represents the incorrect answer, but they are drawn as a solution.				
IV. Inappropriate number of particles, inappropriate arrangement.				
Figure 5. Solution A is less concentrated or has the same concentration as solution B. The number of particles represents the incorrect answer, and the particles of the solvent are drawn organised.				

SS - secondary school; U – university.

Task 2:

Secondary school students as well as university students did poorly in the second task as a whole, since only 9.0% of the former and 5.3% of the latter provided the right answer. The results of the first part of the task showed that 14.8% more of secondary school students than their university counterparts (50.5% of secondary school students and only 35.7% of university students) understood that the number of OH^- particles, in the same volume of the solution, determines the strength of the base in aqueous solutions.

Secondary school students and first year university students have similar misunderstandings about acid-base chemistry. They wrote down the wrong sequence of anion base strengths as X^-, Z^-, Y^- (25.3% of secondary school students; 15.2% of university students). The students from both groups concluded that the fewer hydroxide ions there were in the aqueous solution, the stronger base is the A^- anion. The most common mistakes regarding particles in the solution were: the students did not write down ions (Y^-, Z^- and X^-), but chargeless particles (Y, Z and X – 5.7% of secondary school students; 8.8% of university students), or the whole formulae of sodium salts (NaY, NaZ and NaX – 5.7% of secondary school students; 5.3% of university students).

Only 9.5% of the secondary school students, and even less - only 5.3% of university students - correctly solved the second part of the task. 27.9% more of the university than the secondary school students (20.0% of the secondary school students; 47.9% of the university students) did not even attempt to solve part b) of the task, possibly because they did not understand the question. It can be concluded that students do not understand the acidic or basic properties of salts at the particulate level. They do not know that the numbers of HA molecules and hydroxide ions are equal because of the reaction of A^- with water, ($A^-(aq) + H_2O(l) \rightleftharpoons HA(aq) + OH^-(aq)$).

The most common incorrect answers to the question about the same number of HA molecules and OH^- ions in each box in the second part of the task, are: (a) the solutions are in equilibrium; (b) salts are formed in the process of neutralisation, and (c) sodium salts are neutral. All the answers suggest that students from both groups have misconceptions about the acid-base properties of the sodium salt solutions. Not even 10% of the students from both groups were able to move easily from concepts represented in drawings to verbal descriptions of this submicrorepresentation. Nakhleh made similar observations when she studied high-school students' understanding of acid-base chemistry at particulate level.[21]

Task 3:

Only 8.7% of secondary school and 0.8% of university students correctly solved the whole task. Secondary school students did better in writing the equation of the chemical reaction than did university students (Table 2).

Table 2. Analysis of the equation of chemical reaction (%).

Equation of chemical reaction	SS students	U students
Correctly written equation and aggregate states of matter	**78.0**	**28.8**
Incorrectly written aggregate states of substances	18.7	48.0
Incorrect notation of the compound formulae in the equilibrium reaction	3.3	18.4
Answer not provided	0.0	4.8
Correct symbol for the notation of balanced reaction	**82.0**	**48.8**
Symbol for one-way reaction applied	18.0	47.2

SS - secondary school; U – university.

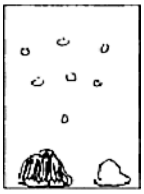
From the analysis of the written recording of the chemical reaction equation (Table 2) we see that much fewer university students than secondary school students (29% *vs* 78%) managed to write correctly the aggregate states of substances in the equation of the chemical reaction. Incorrect formulae of products or reactants were registered in the answers from 3.3% of the secondary school students and 18.4% of the university students, although the students were provided with names of all substances used in the reaction. The conclusion is that the secondary school students were quite well acquainted with the formulae of basic compounds, whereas university students were less competent in this respect. This may be also observed in the number of students who did not solve this part of the task. 47.2% of the secondary school students compared with only 18 % of the university students, knew how to write the symbol for an equilibrium reaction.

In part b), the students were asked to find out how the addition of carbon dioxide impacts on the chemical reaction equilibrium, 20.8% more of secondary school than university students (84.0% of the secondary school; 63.2% of the university students) gave an incorrect answer, while 35.2% of them did not try to solve this part of the task at all.

Table 3a. Errors in part b) of task 3 (%).

	Correct	Incorrect									Without
	0; 1;-1	1;1;1	1;-1;1	1;0;1	1;1;-1	1;-1;-1	1;1;0	-1;1;-1	1;0;0	Other	answer
SS students	**14.7**	8.7	6.7	3.3	15.3	2.7	21.3	5.3	4.7	16.0	1.3
U students	**1.6**	14.4	9.6	8.8	7.2	6.4	3.2	0.8	1.6	11.2	35.2

Table 3b. Correct, and some of the incorrect presentations of parts b) of task 3.

Task part	Correct presentation	Incorrect presentations			
	0,1,-1	0,1,1	-1,1,1	1,1,1	1,1,-1
b)					

SS - secondary school; U – university. 1 – substance amount is increased, 0 – no change of substance amount, -1 – substance amount is reduced, sequence of numbers corresponds to compounds: CO_2, $BaCO_3$, BaO.

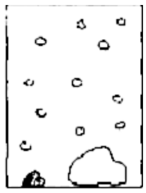
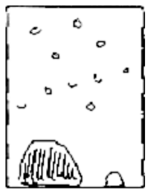
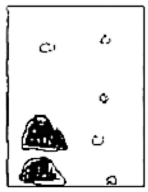
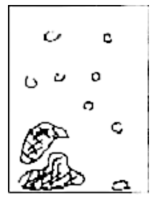
In Table 3a we can observe that 14.7% of secondary school students and only 1.6% of their university counterparts made the correct deduction that upon the addition of carbon dioxide into the system the quantity of barium carbonate increases while the quantity of barium oxide decreases. 8.7% of secondary school and 14.4% of university students solved the task on the basis of the false prediction that upon addition of carbon dioxide the quantity of all the substances would increase. 21.3% of the secondary school students also made the false assumption that the quantity of barium oxide would not change. The same error was made by only 3.2% of the university students; 15.3% of secondary school and 7.2% of university students assumed incorrectly that the quantity of barium oxide would decrease while the quantity of barium carbonate and carbon dioxide increases. The remaining errors (16.0% of secondary school students and 11.2% of university students) are not included among errors listed in Table 2 because they appeared less frequently (< 2%). The reason for these results might be insufficiently clear task instructions.

The secondary school students were better in part c) of the task, where they had to establish the impact of increased temperature on the system in equilibrium (Table 4a).

Table 4a. Errors in part c) of task 3 (%).

	Correct	Incorrect								Without
	1,-1,1	1,1,1	0,-1,1	1,0,1	1,-1,-1	0,-1,-1	0,0,0	1,-1,0	Other	answer
SS students	**60.7**	1.3	1.3	7.3	3.3	1.3	4.7	3.3	10.7	6.0
U students	**19.2**	7.2	5.6	4.0	4.0	3.2	2.4	0.8	14.4	39.2

Table 4b. Correct, and some of the incorrect presentations of parts c) of the third Task 3.

Task part	Correct presentation	Incorrect presentations			
	1,-1,1	1,1,-1	1,1,0	-1,1,-1	0,1,-1
c)					

SS - secondary school; U – university; 1 – substance amount is increased, 0 – no change of substance amount, -1 – substance amount is reduced, sequence of numbers corresponds to compounds: CO_2, $BaCO_3$, BaO.

In contrast to the results in part b) of the task, 60.7% of secondary school students correctly predicted an increase in the product quantity when the temperature is increased. For the university students, however, this part of the task seemed to represent a major difficulty because only 19.2% of them made a correct drawing of how temperature alters the system at equilibrium. 7.3% of the secondary school students and 4.0% of their university counterparts even think that, in the thermic decomposition of barium carbonate, carbon dioxide is released and barium oxide is formed, but that the quantity of barium carbonate remains unaltered. 7.2% of the university students believe that the quantities of all substances in the system - the products as well as the reactants - increase with the increased temperature.

Task 4:

The fourth task was equally challenging for the secondary school students as for their university counterparts, since all three parts were solved correctly by only 3.3% of the former and by none of the latter group.

In part a) only 1.6% of university students and 9.3% of secondary school students managed to translate correctly the submicropresentations into the symbolic chemical language (Table 5). University students made fewer mistakes in writing the equations of chemical reactions, but this could be attributed to the fact that only 6.0% of the secondary school students, compared with 36.0% of the university students, did not even try to write the chemical reaction.

Table 5. Analysis of part a) of the task 4(%).

	Correct chemical equation	Incorrect chemical equation			Without answer
		one-way reaction marked	$4AB+A+3B \rightarrow 2AB+3A+5B$	Other errors[a]	
SS students	**9.3**	30.2	25.1	29.4	6.0
U student	**1.6**	23.6	24.4	14.4	36.0

SS - secondary school; U – university.

[a] Some of the errors: $4AB \rightleftharpoons 2A+2B+2AB$; $3A+5B \rightleftharpoons 2AB$; $B_3+A+4AB \rightleftharpoons 2AB+A_3+B_5$; $A \rightleftharpoons B$; $4AB \rightleftharpoons 2AB$; $2A_5+2B_7 \rightleftharpoons 2A_5B_7$; $A+B+AB \rightleftharpoons A+B+AB$; $A_2+B_2 \rightleftharpoons 2AB$; $BA+AB \rightleftharpoons AB$;…

We established that 64.0% of secondary school students and 57.6% of the university students wrote the equation of the chemical reaction as a one-way reaction, which is incorrect. More secondary school students than their university counterparts (see Table 5) applied the symbol for reversible reaction correctly. 25.1% of the secondary school students and 24.4% of the university students "literally" translated the submicropresentation into a chemical reaction equation ($4AB+A+3B \rightarrow 2AB+3A+5B$) and marked it incorrectly as a one-way reaction. The remaining errors occurred far more often in the group of secondary school students, which could be attributed to the fact that more of them were actually solving the task, which consequently resulted in a higher share of errors. 36.0% of the university students compared with only 6% of their secondary school counterparts did not write down the reaction at all.

In part b) of the task they were asked to define the chemical reaction from an energy point of view; this was done correctly by 17.1% more of secondary school students than their university counterparts (54.7% of secondary school students; 37.6% of university counterparts). Thus we can conclude that neither group was well acquainted with the energy laws in substance changes and did not cleary understand that part a) of the task provides the information that the reaction takes place at increased temperature, therefore it is endothermic. If they had understood the concept of endothermic and exothermic reactions correctly, and had carefully read the text of the task and compared the schematic notes on particles for this reaction under two temperatures, they would have come to the conclusion that the reaction had to be endothermic.

Table 6. Analysis of part c) of task 4 (%).

	Correct (increase)	False assumptions		Without answer
		Does not change	Decrease	
SS students	**40.7**	47.3	12.0	0.0
U students	**27.2**	60.8	6.4	5.6

SS - secondary school; U – university.

Altogether, 40.7% of the secondary school students compared with 27.2% of the university students concluded correctly that the number of substance A atoms increases with the increased volume of the container in part c) of the task. 59.3% of the secondary school students and 67.2% of the university students do not understand the impact of increased volume and with it a decrease in pressure on the equilibrium system, so that the balance shifts in the direction of the formation of a larger amount of substance.

Table 7. Share of correct answers in separate parts of the task (%).

	Task 1			Task 2		Task 3			Task 4		
	a)	b)	c)	a)	b)	a)	b)	c)	a)	b)	c)
SS students	77.6	72.3	46.2	50.5	9.5	78.0	14.7	60.7	9.3	54.7	40.7
U students	68.7	56.1	41.1	35.7	5.3	16.8	1.6	19.2	1.6	37.6	27.2
t	1.5	3.2^b	0.83	4.44^c	3.87^c	15.25^c	4.33^c	8.4^c	2.33^a	2.33^a	2.8^b

$^a p < 0.05$, $^b p < 0.01$, $^c p < 0.001$; SS - secondary school; U – university.

Table 7 shows the results obtained by secondary school students and their university counterparts in separate parts of the tasks. The t-test confirmed statistically significant differences between the two samples of students. Tasks 4a, 2b and 3b – of which the most difficult one turned out to be 4a – were of very high t-values and proved most demanding for both groups. The difference between the two groups is statistically significant, with a 5% risk (we can be sure that in 95% of the cases the difference is statistically significant). The second most difficult task was 2b), in which the difference is also statistically significant, with 0.1% risk. Task 3b) was extremely difficult for university students, whereas secondary school students came out a little better, the statistically significant difference being 0.1% risk. Both groups of students did best in tasks 1a) and 1b), of which only the 1b) part is statistically significant and can be predicted with a 0.1% risk.

Conclusions and implications for chemical education

It can be concluded that secondary school students are more successful in solving this type of tasks than university students are. This may be explained by the fact that the tested secondary school students chose chemistry to be their Matura exam at the end of secondary school and thus had more practice in relevant fields.

In order to solve the above tasks successfully, students must possess basic knowledge of chemistry and the ability to connect macroscopic, submicroscopic and symbolic levels of the relevant chemical concepts.[22] They also have to perform well on the skills that are required for solving particulate problems. Students are better in solving the problems that involve reading of the submicrorepresentations, but are less successful in solving tasks where drawing of particulate schemas are required and translations of the submicrorepresentation of the phenomena to their symbolic representation.

On the basis of the results we can conclude that teachers do not connect these three levels sufficiently and that they focus on them primarily when preparing students for the Matura exam. The knowledge of the students who had chemistry as their Matura exam does not reflect the average knowledge of chemistry which other students possess at the end of secondary school. Before the introduction of new concepts, the teacher should first establish what the students already know. In case of misconceptions, the teacher must first clarify these and only then add new concepts and their connections to the conceptual structure of the individual. Chemical thinking requires knowledge about how to connect macroscopic findings with the explanations at the submicroscopic level and their recordings at a symbolic level. Unless this is achieved, chemical education results only in fragmentary knowledge, which is quickly forgotten. This is accompanied by a feeling that chemistry is difficult to understand, which does not improve student motivation. The results of the research show (Table 7) that secondary school students come during the Matura exam preparations in contact with submicrorepresentations more frequently than in the basic chemistry lessons before the Matura exam preparations. Those students who did better in solving tasks on submicrorepresentations possess chemical knowledge developed at a higher cognitive level. To achieve this, it is far better to cover fewer concepts, but to endeavour to connect the macroscopic world with the microscopic world of particles and with symbolic recordings in basic chemistry lessons in secondary school education. It is also recommended that teachers conduct informal evaluation more frequently with open-ended items, including submicrorepresentations, since in such items students have to explain their decisions for designing the submicrorepresentations. From these explanations the teacher would get information about students´ ways of thinking about specific phenomena. On these bases the teacher could choose an appropriate further teaching strategy to avoid possible misunderstandings of chemical concepts.

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Povzetek

Namen raziskave je bilo ugotoviti uspešnost srednješolcev, ki so izbrali kemijo kot maturitetni predmet in študentov prvega letnika fakultete pri reševanje problemov, povezanih z osnovnimi kemijskimi pojmi o raztopinah, kislinah in bazah in ravnotežjih s pomočjo submikroreprezentacij. Pri reševanju tovrstnih nalog so bili uspešnejši dijaki, ki so opravljali maturo iz kemije, ker so obravnavali kemijske pojme s povezovanjem treh ravni kemijskih pojmov (makro, submikro in simbolna raven) pri pripravah na maturo. Ta način učenja in poučevanja pri pouku kemije v naših srednjih šolah ni pogost. Za doseganje višjih kognitivnih ravni pa bi bilo priporočljivo pri pouku v večji meri povezati vse tri ravni razumevanja kemijskih vsebin.