sciendo

DOI: 10.1515/cdem-2018-0006 CHEM DIDACT ECOL METROL. 2018;23(1-2):97-111

Miroslav PROKŠA[1], Anna DROZDÍKOVÁ[1] and Zuzana HALÁKOVÁ[1*]

LEARNERS' UNDERSTANDING OF CHEMICAL EQUILIBRIUM AT SUBMICROSCOPIC, MACROSCOPIC AND SYMBOLIC LEVELS

UCZNIOWSKIE ZROZUMIENIE RÓWNOWAGI CHEMICZNEJ NA POZIOMIE SUBMIKROSKOPOWYM, MAKROSKOPOWYM I SYMBOLICZNYM

Abstract: It is not easy for secondary school learners to comprehend the concept of chemical equilibrium at the level of understanding. In this context, a feedback is important for the teachers to optimize their help to students in constructing this concept. We designed and tested sets of particularly prepared tasks, the solution of which reflects the depth of understanding of the basic concept in macroscopic, submicroscopic and symbolic representation. Difficulties in understanding the chemical phenomena and concepts do not result only from the existence of these three levels or from their explanation using abstract concepts, but also from the lack of interconnection between these representations. Consistent interconnection of these levels can lead to an internal conflict in students, and consequently to a more profound understanding of the concept or relationships between concepts at multiple levels of representation to understand them or to change the meaning of one to another. There is also a close connection with the aspect of memory, algorithmic and conceptual approaches to solving educational situations, which extends dimensionally and reinforces the need for a more comprehensive grasp of learners' mastery of the given concept. The teacher cannot expect that the learners without intensive training, e.g., only by observing the macroscopic representation, can interpret the essence of the submicroscopic representation. Therefore, these aspects need to be consistently involved in the model of learners' cognitive process early enough to apply them in the educational practice without any problems.

Keywords: chemical equilibrium, equilibrium constant, chemical triangle, level of comprehension

Introduction

A good feedback is the basic prerequisite for improving the education outcomes. Therefore, the attention of the didactic community is focused on the recognition of the quality of curriculum comprehension. There have been several streams regarding this issue registered so far. One of them was to find out the level of understanding of chemical concepts in learners. Several authors have tried to reveal what concepts are problematic for students to understand and why, whether it is abstractness of the concept,

---

[1] Department of Didactics in Science, Psychology and Pedagogy, Faculty of Natural Sciences, Comenius University in Bratislava, Mlynská dolina, Ilkovičova 6, 842 15 Bratislava, Slovak Republic, phone +421260296311

[*]Corresponding author: halakova@fns.uniba.sk

non-understanding of the essence, the meaning, the representation of the concept, or any other factors which can account for it. At present, the related research is primarily carried out via identification and detection of misconceptions. As early as at the end of the last century Nakhleh and Mitchell [1] pointed out to this risk that most learners understand chemical concepts only at the level of memory or algorithmic mastery, while the minority of them is also able to achieve the conceptual grasp of the given concept. At the same time, the algorithmic approach discourages learners from conceptual understanding [2] and prevents them from solving the problem.

A broad spectrum of concepts in chemistry brings a number of problems in their understanding by learners. Misconceptions in general and physical chemistry have been studied very thoroughly as follows: topics such as gas laws (Charles Law, Boyle's Law), stoichiometry [1, 2], chemical equations, empirical formulas, density, Bohr atomic model, Heisenberg principle [3], electrochemistry, chemical kinetics, acids and bases, chemical bonding [4], redox reactions. Even macroscopic and microscopic understanding of the concepts by 7-10 years old children [5] was studied in the field of states of matter, particle composition of matter, phase changes and dissolving. The understanding of all three levels was studied by Hinton, Nakhleh [6] in the topic of chemical reaction, Ghirardi et al. [7] in the topic of chemical equilibrium.

In the curriculum of general chemistry, the concept of chemical equilibrium is considered one of the most difficult to understand and yet one of the most important [8-10]. Several researchers justify this fact by its abstraction, interconnections with other hierarchically subordinate concepts [11] such as system, reaction, mixing, reversibility, dynamics [12] as well as by the fact that the chemical equilibrium is the basis for understanding of other chemical concepts (acids, bases, solubility, redox reactions, etc.) [13]. Moreover, many students also classify the chemical equilibrium among the concepts difficult to understand [14].

In the field of chemical equilibrium, researchers have identified several misconceptions. For example, Pedrosa and Dias [12] identified 33 problematic words or phrases in Portuguese chemistry textbooks; Bilgin et al. [14] highlighted 10 areas in chemical equilibrium where misconceptions arise. Other misconceptions concern the approach to chemical equilibrium, characteristics of chemical equilibrium, understanding the conditions of change in chemical equilibrium, the role of a catalyst [14], the notion that the reaction can proceed backward only if the forward reaction is terminated [15] as well as predicting the conditions of equilibrium [16]. They also include distinction between the conditions that characterize completion and reversible reactions, the impact of factors on the value of the equilibrium constant as well as an idea that in a state of chemical equilibrium there is a simple arithmetic/linear relationship between the concentrations of reactants and products [17]. According to [14], the topic of chemical equilibrium is unique because when teaching the misconceptions may occur due to the similarity with everyday experience as well as the abstractness of this phenomenon.

Feedback is essentially conditioned by the quality of the resources used. Even in this area some developmental trends can be observed, while exploring the depth of understanding requires the design and use of specific tools. One of the first tools applied to measure the understanding of concepts in chemistry - based on the use of non-mathematic conceptual tasks in a two-level test including multiple-choice tasks based on understanding the representation of a phenomenon or concept and a subsequent concept justification - was the test used in the 90's by Mulford [18] named the CCI (Chemistry Concept Inventory) and should have indicated the level of misconceptions in general chemistry in undergraduates.

The depth of understanding of chemical concepts has been monitored through conceptual tasks and two-level tests for a long time. Two-level tests make it easier to identify misconceptions in learners and examine them more precisely on a larger sample of respondents. The first level consists of a multiple-choice task and the second one requires the justification of the choice in the first level [19]. Although there is a risk of guessing the answer and random selection of answer, this problem has already been solved by introducing a third level [20], where respondents should show their certainty by expressing their attitude to a given problem and concept comprehension. Advantages of conceptual tasks and two-level tests is the use of so-called Concept inventories that contain multiple-choice tasks (many of them are two-level ones) and are used to indicate the level of misconceptions in learners. In general, they were used as criteria tests to determine the current level of learners’ knowledge in a selected area. Since the 1990s many of them have been designed with a focus on the comprehension of science concepts: Multiple-choice mechanics diagnostic test, Force Concept Inventory (FCI) [21], Energy Concept Inventory, Chemistry Concept Inventory [18], Biology Concept Inventory (BCI) [22], Molecular Life Science Concept Inventory, Science Literacy Concept Inventory. Farand and Tavares [23] elaborated the concept inventory including more than 800 tasks in 10 subcategories to evaluate the knowledge of students in chemical engineering involving the topic of chemical equilibrium in several subcategories. The use of pairing tasks technique (one algorithmic and analogical conceptual) was also considered important in identification of the depth of understanding of chemical concepts by novice undergraduates.

Our aim is to contribute to this issue by improving the feedback, as well as by designing and verifying the application of specific measuring tools to allow for a deeper insight into the understanding of chemical equilibrium concepts.

Research conducted all around the world also points out to the fact that children, learners [14], pre-service [8, 16] as well as in-service chemistry teachers [8] face a problem with understanding the submicroscopic and symbolic levels of chemical equilibrium, because they are abstract and the students as well as the teachers miss sufficient experience with them. The most common measuring tools to detect the chemical equilibrium misconceptions include either two-level tests, open-question interviews or worksheets.

Aims and objectives

In our research we have set the aim to comprehensively understand learners’ knowledge of chemical equilibrium after the initial information about the chemical concept to redesign the basics of innovative approaches focused on the enhancement of this part of the didactic system of chemistry teaching. Our partial goal was to find out the depth of grasp of this concept at the level of macroscopic, submicroscopic and symbolic interpretation in their interconnection. Our research should also reflect the student's grasp of this chemistry topic at the level of memory reproduction, algorithmic mastery and conceptual comprehension, and recognize the interdependence of these levels.

Although we conducted the research on Slovak learners, so we worked with the Slovak didactic system, we are convinced that despite the uniqueness of each didactic system in different countries and different material and economic backgrounds, there is still enough common attributes that can be applied in a more general context regardless of the differences mentioned.

Regarding these goals, we set the following research questions:

1. How do the 16-year-old learners master the concept of chemical equilibrium after the initial experience with a given chemistry topic in terms of macroscopic, submicroscopic and symbolic interpretation and their interconnection?
2. What is the extent of learners’ memory, algorithmic and conceptual mastery of the related concept?

Methodology of research

As a research tool five sets of tasks were used in our research.

Since all subtasks of one set were based on the same problem given in the assignment, it allows us to understand the learners' comprehension of the key aspects of chemical equilibrium much better. At the same time we tried to take advantage of the character and benefits of conceptual tasks.

The individual topics concerned the understanding of reversible reaction, equilibrium constant and the impact of temperature, pressure, and change of concentration on stabilizing the new equilibrium.

Each set consisted of subtasks reflecting the memory reproduction, algorithmic level and conceptual mastery of selected nodes related to chemical equilibrium. From another point of view, each set of tasks involved at least two levels of representation of the studied knowledge at the same time - the combination of macroscopic, submicroscopic and symbolic levels of representation. In terms of the subtask format, there were two format types - either open-ended questions, or a multiple choice.

The objectives of individual sets of tasks were structured in order to check conceptual mastery of the concept of chemical transformation, to identify the understanding of a concept of incomplete chemical change, reversibility of some reactions, to recognize the conceptual mastering of the state of chemical equilibrium for reaction systems at different temperatures, especially in the context of algorithmic knowledge about how to determine the thermal effect of reactions and an algorithm for shifting the chemical equilibrium due to changes in temperature, to map the state of the conceptual mastering of the equilibrium constant in the context of interpreting the extent of metabolism, to detect the conceptual mastery of the impact of pressure and concentration on the equilibrium system.

The entire set contained five sets of tasks including 15 subtasks in total. The subtasks were divided into individual interpretations as follows: 6 concerned submicroscopic interpretation, 6 symbolic and 3 macroscopic interpretation of the essence of chemical equilibrium. The students could have achieved maximum 4 points per each subtask, 60 points in total.

Descriptive statistics

Here are some of the characteristics of our research tool. The data obtained were processed by Excel and Statgraphics 17.1.08 and the descriptive characteristics - sensitivity via Ferguson's δ and reliability via Cronbach's α - were calculated. The value of Ferguson's δ equals to 0.96, and since the value is greater than 0.90, it means that the research tool is sensitive enough.

To evaluate the reliability of the research tool we used Cronbach's α. The value of 0.57 does not exceed the value of 0.7 at which the test is regarded to be reliable. Nevertheless, we considered this value as acceptable, because the research tool has mainly a diagnostic function.

In order to ensure the content and face validity, we asked teachers to evaluate the test. The test was assessed by four university teachers of chemistry and didactics of chemistry and five secondary school chemistry teachers. Experts consider the created research tool valid to find out the depth of understanding the concepts related to chemical equilibrium.

Research

The research was done at Slovak schools in 2017. The measurement was carried out half a year after the related topic was taught to the students. The learners had a 45-minute limit to complete the test, but most of them managed it within 30 minutes. Altogether, 22 classes from eight Slovak schools were involved in the research including 473 secondary school learners (about 16-year-old ones). The learners came from 15 different teachers.

Results and discussion

Phenomenon analysis

Due to the lack of space, we provide a sample of two sets of tasks as well as the phenomenon analysis of their solutions. We intentionally selected two examples that differ both in the character of the subtasks and focus. The first example is the set of tasks that aimed at the interconnection of submicroscopic and symbolic representation of chemical processes. It contains multiple-question tasks.

The second example is the set of tasks including open questions and focused on the interconnection of symbolic and macroscopic representation.

Example 1 - assignment

1. The first two figures show the condition before mixing the substances.

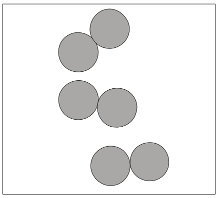


Fig. 1

+

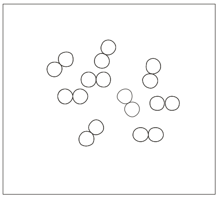


Fig. 2

The third figure shows the condition after mixing.

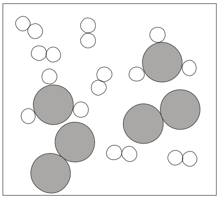


Fig. 3

Circle the correct answer.

1.1. What do the figures describe?
  a) no conversion of substances
  b) physical change
  c) mechanical mixing
  d) chemical change
1.2. What conversion is shown in the figures?
  a) irreversible
  b) reversible
  c) backward
  d) no conversion
1.3. Changes displayed in the figures can be symbolically written down as
  a) $A_2 + 3B_2 \rightarrow 2AB_3$
  b) $3A_2 + 9B_2 \rightarrow 2AB_3$
  c) $A_2 + 3B_2 \rightleftharpoons 2AB_3$
  d) it is impossible to write it down

The Set of Tasks 1 demonstrated in the first example focused on identifying the conversion of substances based on its graphical visualization and on the symbolic record of the equilibrium reaction.

In Task 1.1 about 72.5 % of learners correctly identified that the figures displayed a chemical change, since the original bonds were broken and new ones were formed. The remaining 27.5 % either did not answer the question or thought it concerned no conversion of substances or a physical change. However, the largest part of incorrect answers (62 %) was represented by the one regarding the depicted phenomenon as a mechanical mixing. This group of learners either did not realize that mechanical mixing does not lead to a break-down or formation of new bonds or they were unable to understand the Figure 3, which showed a different arrangement of atoms. Overall, it can be stated that in terms of submicroscopic representation the learners demonstrated the understanding of the essence of a chemical reaction.

We based the analysis of Task 1.2 on a postulate that the learners, who had not identified a chemical change in Task 1.1, were working with a wrong initial assumption. Therefore, we decided to analyze only the answers of that group, which solved the first task correctly. Only 24.7 % of these learners stated that the figures show a reversible reaction. The largest group (up to 64.5 %) did not realize the incomplete conversion of the starting materials into the products even though both reactants remained in the reaction mixture. Thus, they opted for a one-direction reaction as their answer. A smaller group (7.4 %) claimed that it is a backward reaction, which may be related to the mix-up of the concepts of backward and reversible reaction.

Task 1.3 focused on identification of learners' understanding of the chemical reaction at the level of a symbolic representation. Out of the learners, who correctly stated that the reaction was reversible in the previous step, there were 55.4 % of those who also correctly selected the symbolic record of the reaction. A smaller number of learners (16.9 %) chose an alternative that showed a one-direction reaction, and up to 26.5 % opted for the answer with all the molecules depicted in the figure on the side of reactants, i.e. also molecules which did not react and thus "were not involved” in the reaction. Only about 1.2 % of learners stated that it is impossible to write down the conversion.

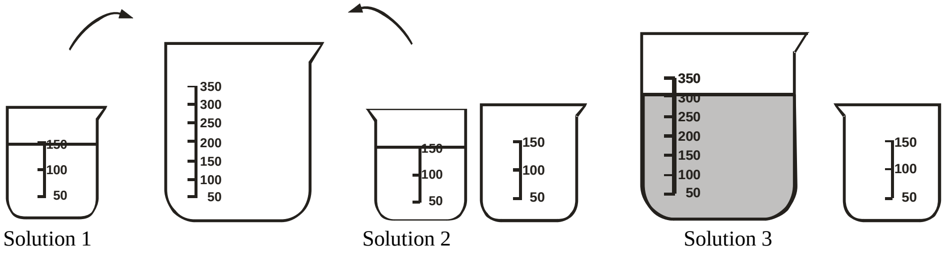
Overall, the analysis of the Set of Tasks in the first example has shown that most learners can identify a chemical change at the submicroscopic level from the figures, but do not realize that in most chemical reactions there is incomplete conversion of the reactants into the products, and thus the reactions run as reversible rather than in one direction. Almost half of all learners, regardless of their previous answers, wrote down in their symbolic record all the molecules depicted in Figure 3.

In total, only 9.7 % of learners followed the following thought line: the figures show a chemical change (first part) that is reversible (second part) and its symbolic record is $A_2 + 3\,B_2 \rightleftharpoons 2AB_3$ (third part).

It results from this analysis that although the learners partially understand the attributes of this aspect of chemical reactions (in particular, identifying the chemical reaction at submicroscopic representation level), they miss other attributes (the lack of differentiation between one-direction, reversible or backward reaction). Moreover, learners' grasp of quantitative ratios of the reaction in a symbolic representation is also insufficient (the lack of differentiation between the starting amount of substance and the amount of substance in the stoichiometric ratio of reactants and products). In other words, the way of how this set of tasks was solved has indicated significant shortcomings in the conceptual mastery of the related aspects of chemical reactions.

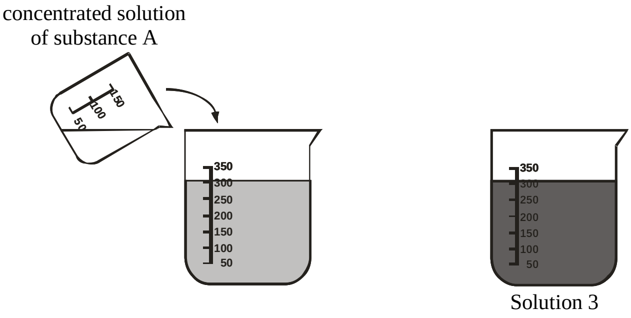
Example 2 - assignment

The figure illustrates the procedure of a chemical experiment leading to equilibrium state in solution 3 after the solution 1 containing the dissolved substance A and solution 2 containing the dissolved substance B are mixed together.



2.1. Write down a general chemical equation, using the letters A, B …, in order to express the essence of the experiment

If a small amount of a more concentrated solution of substance A is added to the solution 3 in the next step, we will observe a following change:



2.2. Explain the essence of the observed effect.
2.3. What is another way of achieving a similar effect to that in the previous step?

The concept of chemical equilibrium in terms of the change in equilibrium due to the addition of the reactant was examined in the Set of Tasks 2 in the second example. We focused on this phenomenon from the view of the combined macroscopic and symbolic representation. Regarding the difficulty of the tasks it concerned algorithmic and conceptual level.

The results suggest that the learners can transform the information provided in a graphical visualization depicting the equilibrium-shift experiment to a symbolic level well enough (80.7 %). Unfortunately, the recording of the equilibrium state was considered inadequate. The reversibility of the chemical reaction was showed in minimum in the symbolic record (2.3 %). This suggests a weak anchoring of the reversibility of chemical reactions in learners' comprehension and, at the same time, a lack of experience in recording the reversible reactions.

Because of the success of Task 2.2 solution, it can be said that the relatively good symbolic representation and mastering of the algorithm for recording the chemical equation of one-direction chemical reactions does not mean the adequate conceptual understanding of chemical equilibrium. In Task 2.2 the learners, who were supposed to interpret the nature of the graphically depicted observation of the chemical experiment, were less successful. It is evident that absent responses (15.2 %) and the solutions that were not based on chemical equilibrium (57.3 %) prevailed in this task. Majority of incorrect explanations were not based on respecting the fact that it is an equilibrium system. The missing notice of the reversible reaction in the chemical equation in the symbolic representation was probably not accidental. It did not result from the lack of attention or inconsistency of the learners.

It can be concluded from the analysis of this task that most erroneous answers, in fact, did not involve any explanation. It was a different way of describing the observation (darkening of the solution after adding the reactant). Other incorrect answers reported that there was an increase in the product concentration, but the explanation of the gist of observation was not explicitly completed. Another unacceptable answer - that the darkness of solution was caused by a faster reaction, etc. - was also monitored in a relatively big number of cases. The analysis suggests a problem of learners with the conceptual grasp of the essence of chemical equilibrium.

One of very interesting findings was that in Task 2.3 up to 18 % of learners were able to appropriately suggest an adjustment of the experimental procedure that would lead to a similar result to that in the assignment.

The rest of students either did not solve the task or their suggestion was wrong. The three-fold representation of an acceptable solution in learners' answers in Task 2.3, compared to the proven understanding of the essence in Task 2.2, suggests that a certain number of learners, even without a real comprehension of the problem, can propose an acceptable solution due to their ability to apply the analogous procedure.

The overall interpretation of the analysis of the Set of Tasks 2 results in the second example revealed a weak mastery of students' interconnection of macroscopic and symbolic representations of chemical equilibrium.

Conceptual understanding of the new equilibrium after intervention in the original equilibrium state does not affect the positive results of drilling the symbolic record of a chemical reaction. A significantly weaker anchoring of the record of reversible reactions can be identified also in the results of this algorithmic level (partially perhaps also a memory one) of mastering the given chemistry concept. Apparently, less attention (or time spent in the lessons) is paid to this issue and therefore it is not sufficiently built in the knowledge structures of learners.

In macroscopic representation, the learners can propose an acceptable solution to affect the equilibrium even without sufficient conceptual mastery of the equilibrium from this point of view. This is positive enough, but still we set higher goals when teaching. The analysis of learners' answers also indicates the occurrence of misconceptions associated with the lack of differentiation between the effect of concentration change on the rate of a chemical reaction and the effect of concentration change on the establishment of a new equilibrium in the equilibrium system.

Quantitative analysis

Our quantitative analysis of the obtained results starts with the descriptive characteristics of the obtained data set (Table 1). The total number of learners enrolled in the research was 473. Since all tests were not completely filled in (some of the learners either did not report gender or chemistry mark), various counts were dealt with in further analyzes. In each analysis, only the tests that were completely filled in with respect to the observed characteristic, were taken into consideration.

Table 1

Descriptive characteristics of the data set

Descriptive characteristics of the data set	
count	473
success rate [%]	51.6
arithmetic mean	31.0
modus	29
median	30
standard deviation	6.16
max.	50
min.	16

Of the total 60 points the learners achieved an average of 30.96 that accounts for a 51.6 % success rate. Based on this result, it is evident that, on average, about half of the tasks on the chemical equilibrium were not solved by the learners. Although we accept the fact that this kind of test was new in many ways for the learners, the results suggest a low level of understanding the concept of chemical equilibrium, and therefore the approach of its inclusion in the learning process will require some innovation.

In the second step of the analysis we tried to find out whether there are differences in the performance of learners in submicroscopic, symbolic and macroscopic interpretation of the chemical equilibrium concept.

As it can be seen in Table 2, the learners were the most successful in solving the tasks related to symbolic interpretation and the least successful in those based on macroscopic interpretation. This can be explained by the fact that the symbolic interpretation is given considerable attention in the Slovak didactics system, although it is rather based on the use of memory or simple algorithms. In addition, a portion of the point gain in the tasks about the symbolic level could also have been obtained through the memory and algorithmic level, which eventually was reflected in the overall point gain in this part of the results. Although, in our opinion, the macroscopic level should have been the closest to the learners, the results show that the learners faced the biggest problems exactly when solving these tasks. The reason may be that there is insufficient attention paid to the observation of experiments and a follow-up interpretation. As a result, the learners are unable to capture the relevant facts in this context and draw reasonable conclusions.

Table 2

Success rate of learners in individual interpretations

Interpretation	**Symbolic**	**Submicroscopic**	**Macroscopic**
success rate [%]	58.5	55.8	29.4

The significance of differences in learners’ performance in individual interpretations was examined using a paired *t*-test (Table 3) and it was found out that the differences in all pairs of interpretations were statistically significant.

Table 3

Comparison of learners' performance in different interpretations

Interpretation	***t***
Submicroscopic - symbolic	3.45**
Submicroscopic - macroscopic	77.29**
Symbolic - macroscopic	21.70**[2]

** Statistically significant difference at the level of 0.01

We also examined the tightness of the relationship between the individual interpretations by means of correlations. We used Spearman's correlation coefficient, as the processed data did not meet the normal distribution criteria.

As it can be seen in Table 4, there is a statistically significant relationship between each pair of examined interpretations. Differences, however, are observed in the tightness of relationships. The closest relationship was recorded between symbolic and submicroscopic interpretation with R = 0.42. We can designate this relationship as a moderate correlation. The lowest value R = 0.29 was indicated between submicroscopic and macroscopic interpretation of the essence of chemical equilibrium. The results suggest that these are other aspects of mastering the concept of chemical equilibrium and therefore, the tightness of their relationships is limited only to moderate or low levels.

Table 4

Correlations of learners' performance in individual interpretations

Interpretation	***R***
Submicroscopic - symbolic	0.42**
Submicroscopic - macroscopic	0.29**
Symbolic - macroscopic	0.33**

** Statistically significant difference at the level of 0.01

---

[2] In this case, the Sign Test was used for comparison because the processed data did not meet the conditions for normal data distribution

One of our research goals was also to explore the success rate with regard to the internal structure of the monitored set of learners.

Firstly, our effort was to observe if there are differences in understanding the concept of chemical equilibrium in submicroscopic, symbolic and macroscopic interpretation between the genders. In the analysis, 244 girls and 159 boys were included. Since the data obtained in both groups did not meet the criteria for normal distribution, a non-parametric test, namely the Mann-Whithey (Wilcoxon) *W*-test was used to compare the medians of the two groups.

As it can be seen in Table 5, in submicroscopic and symbolic interpretation no statistically significant difference between the genders was recorded. The statistically significant difference was noticed only in macroscopic interpretation when the boys were significantly better than girls. We can assume that it results from the fact that boys are more oriented towards practical activities and related experimentation and observation than girls.

Table 5

Comparison of boys' and girls' performance

Girls vs. boys	**Submicroscopic**		**Symbolic**		**Macroscopic**	
	girls	boys	girls	boys	girls	boys
median	14	14	14	13	2	4
W-test	19482.0		18876		21665.5*	

* Statistically significant difference at the level of 0.05

Another potential difference in the level of individual interpretations among learners was assumed in relation to the overall learning outcomes represented by the classificatory assessment of teachers. The tested sample was divided into "A-grade learners" (174 learners) and the others (277 learners) rated by teachers with a worse grade.

The analysis showed (Table 6) that the learners evaluated by their teachers as excellent achieved statistically significantly better results in all monitored sections - symbolic, submicroscopic and macroscopic interpretation. It suggests that the level of all three interpretations of the gist of chemical equilibrium in a given research tool corresponds with other tools characterizing the learner's performance in chemistry. The best learners show statistically significantly better results in all interpretations.

Table 6

Comparison of learners' performance and teachers' evaluation

A-grade learners vs. other learners	**Submicroscopic**		**Symbolic**		**Macroscopic**	
	A-grade learners	other learners	A-grade learners	other learners	A-grade learners	other learners
median	14	12	15	13	4	2
W-test	19742.5**		16033.0**		20627.5**	

** Statistically significant difference at the level of 0.01

In the last analysis, the learners, based on the success rate in symbolic interpretation tasks, were divided into two roughly equally large groups of the better ones (those with 14 or more points out of 24) and the worse ones (those with 13 or less points). The group of more successful learners was represented by 231 learners and the other group by 242 learners. As a discriminatory criterion, the division by symbolic interpretation was chosen, as this one was solved by the learners the best, as shown in the previous analysis. In the next analysis, the results of the formed groups regarding the performance in submicroscopic and macroscopic interpretation were compared.

Thus, we wondered whether the learners who are better at writing the phenomena at a symbolic level are also better in submicroscopic and macroscopic interpretation. The results of the created groups were compared using Mann-Whithey (Wilcoxon) *W*-test because the data sets showed deviations from the normal distribution. As it can be seen in Table 7, at both compared levels - submicroscopic and macroscopic interpretation - there are statistically significantly better learners who achieved better results also in symbolic interpretation. When taking into consideration the fact that, in symbolic interpretation tasks the learners used mainly memory or algorithmic methods, and in other interpretations, especially conceptual mastery, based on the obtained results it can be assumed that those learners, who applied memory and learned algorithms better, also showed a better conceptual mastery of the concept of chemical equilibrium in submicroscopic and macroscopic interpretation.

Table 7

Comparison of learners' performance according to a symbolic level

Weaker vs. better learners according to a symbolic level	**Submicroscopic**		**Macroscopic**	
	weaker ones	better ones	weaker ones	better ones
median	12	14	2	4
W-test	38020.0**		35444.0**	

** Statistically significant difference at the level of 0.01

Conclusions

The use of the research tool in our research has brought several interesting facts. From the results of phenomenon analysis concerning the understanding the concept of chemical equilibrium, we can conclude that that learners can understand correctly the information they are provided in graphical visualization of submicroscopic representation of the chemical reaction. They can distinguish between physical and chemical changes. However, they are significantly weaker at realizing the incompleteness of chemical transformation from the information provided such way. As a result, their comprehension of the terms of forward, backward or reversible reaction is much worse. It was indicated by learners' mistakes in symbolic record of the provided submicroscopic representation in the chemical equation. The interconnection of submicroscopic and symbolic representation does not seem to be appropriate, probably due to the absence of necessary memory knowledge and the use of suitable algorithms, but an incorrect deeper understanding of the given phenomenon may also be a reason. Thus, the conceptual grasp of the concept of equilibrium system seems to be inadequate.

In terms of identifying the understanding and using the concept of equilibrium constant we can again state that learners are relatively satisfactorily able to recognize the relationship for the equilibrium constant of the given system from the provided graphical visualization of the submicroscopic representation, also that it is the equilibrium system but when it is necessary to involve the memory knowledge and algorithmic methods, they are weaker at writing the equilibrium constant of the given system in a symbolic representation.

They fail considerably in solving the requirement to calculate a numerical value of the given equilibrium constant from the information provided as well as to draw conclusions about the given equilibrium system from its value. We can state the weak conceptual grasp of the concept of equilibrium constant, although the learners do fairly well in memory knowledge and algorithms. One of the causes behind the detected situation is probably also the weak interconnection of submicroscopic and symbolic representation.

When assessing the performance of learners regarding the influence of the equilibrium by change in temperature, we found out that from the provided graphical visualization of submicroscopic representation of the equilibrium system at different temperatures a significant majority of learners can determine that it is a change in the equilibrium due to a change in temperature. Likewise, in majority cases the learners chose the right answer in relation to the equilibrium constant at different temperatures, in claiming the exo- or endothermic nature of the forward reaction, and also in determining the impact of temperature changes on the equilibrium system. The advantage of multiple verification of this knowledge in the used research tool is that we can identify random factors that distort the result. At the same time, only a third of the learners answered correctly the both tasks dealing with the temperature impact on the equilibrium system correctly. This suggests a possible isolation of learners' knowledge and algorithms, but it is rather the impact of random correct answers in individual subtasks allowed by multiple-task character of individual subtasks in this set of tasks. Despite a relatively high number of correct answers in all of subtasks, we tend to be on the side of weak conceptual understanding of this aspect of chemical equilibrium.

Another attribute of chemical equilibrium that was examined in the Set of Tasks 4 was the influence of pressure on the equilibrium system. In the informative introduction to the situation, we combined submicroscopic and symbolic and, in part, also macroscopic representation of the graphically visualized equilibrium system. Regarding the character of subtasks, we had selected the two-level test ones. Even in this set, the learners had no problem to identify the submicroscopic representation of equilibrium system. They also master the symbolic representation of this system as well as the algorithms to solve the given situation. Nevertheless, only a fifth of them could combine all these attributes in the conceptual solution of the set.

In the last set of tasks, we focused on learners' understanding of the impact of concentration on chemical equilibrium. The results indicate that a good mastery of macroscopic and symbolic representation of a given situation does not yet mean a conceptual grasp of a given attribute of chemical equilibrium. Learners' answers also indicate the mastery of necessary algorithms, but also the lack of real understanding and ability to apply the presented knowledge. The conceptual grasp of the given concept will require change both in the teaching and learning processes of this part of chemistry education.

We can say that it is the phenomenon analysis of the research results that leads us to the above conclusion.

Moreover, the quantitative analysis of the collected data suggests that the change in the education conception including this part of chemistry has been required by all learners involved in the analysis - girls, boys, excellent and weaker learners, both successful and unsuccessful ones in solving the tasks of the applied research tool.

We believe that the approach introduced by Ghirardi et al. [7] might be a suitable starting point in this endeavor for change. However, a whole series of further research on this issue will still be needed. From the analysis of our research, it can be stated that the learners' understanding of submicroscopic, macroscopic and symbolic representation of the observed chemistry concept is somewhat related to one another, but their correlation is not very significant. This conclusion will have to be respected in the educational process. Similarly, it also seems to be related to the interconnection of memory, algorithmic and conceptual levels. The mastery of individual levels and representations will have to be meaningfully combined in active and intensive application by learners. Otherwise, the learners will be able to memorize the definitions, theorems, the algorithms, but they will still miss the real essence of chemistry concepts.

Acknowledgement

This research was realized with a support of Grant VEGA 1/0166/16.

References

[1] Nakhleh MB, Mitchell RC. Concept learning versus problem solving there is a difference. J Chem Educ. 1993;70(3):190-192. DOI: 10.1021/ed070p190.

[2] Nurrenbern SC, Pickering M. Concept learning versus problem solving: Is there a difference? J Chem Educ. 1987;64(6):508. DOI: 10.1021/ed064p508.

[3] Tsaparlis G, Papaphotis G. High-school students' conceptual difficulties and attempts at conceptual change: The case of basic quantum chemical concepts. Int J Sci Educ. 2009;31(7):895-930. DOI: 10.1080/09500690801891908.

[4] Luxford CJ, Bretz SL. Development of the bonding representations inventory to identify student misconceptions about covalent and ionic bonding representations. J Chem Educ. 2014;91(3):312-320. DOI: 10.1021/ed400700q.

[5] Nakhleh MB, Samarapungavan A. Elementary school children's beliefs about mater. J Res Sci Teach. 1999;36(7):777-805; DOI: 10.1002/(SICI)1098-2736(199909)36:7<777::AID-TEA4>3.0.CO;2-Z.

[6] Hinton ME, Nakhleh MB. Students' microscopic, macroscopic, and symbolic representations of chemical reactions. Chem Educator. 1999;4(5):158-167. DOI: 10.1007/s0089799032.

[7] Ghirardi M, Marchetti F, Regis CAR, Roletto E. Implementing an equilibrium law teaching sequence for secondary school students to learn chemical equilibrium. J Chem Educ. 2015;92(6):1008-1015. DOI: 10.1021/ed500658s.

[8] Őzmen H. Determination of students' alternative conceptions about chemical equilibrium: a review of research and the case of Turkey. Chem Educ Res Pract. 2008;9(3):225-233: DOI: 10.1039/b812411f.

[9] Garnett PJ, Garnett PJ, Hackling MW. Students' alternative conceptions in chemistry: a review of research and implications for teaching and learning. Studies Sci Educat. 1995;25(1):69-95. DOI: 10.1080/03057269508560050.

[10] Solomonidou C, Stavridou H. Design and development of a computer learning environment on the basis of students' initial conceptions and learning difficulties about chemical equilibrium. Educat Infor Technol. 2001;6(1):5-2. DOI: 10.1023/A:1011359010331.

[11] Quilez-Pardo J, Solaz-Portoles JJ. Students' and teachers' misapplication of the Le Chatelier's principle: implications for the teaching of chemical equilibrium. J Res Sci Teach. 1995;32(9):939-957. DOI: 10.1002/tea.3660320906.

[12] Pedrosa MA, Dias MH. Chemistry textbook approaches to chemical equilibrium and student alternative conceptions. Chem Educ Res Pract Eur. 2000;1(2):227-236. DOI: 10.1039/A9RP90024A.

[13] Voska KW, Heikkinen HW. Identification and analysis of student conceptions used to solve chemical equilibrium problems. J Res Sci Teach. 2000;37(2):160-176. DOI: 10.1002/(SICI)1098-2736(200002)37:2<160::AID-TEA5>3.0.CO;2-M.

[14] Bilgin I, Uzuntiryaki E, Geban Ö. Students' misconceptions on the concept of chemical equilibrium. Educat Sci. 2003;28(127):10-17.

[15] Niaz M. Response contradiction: conflict resolution strategies used by students in solving problems of chemical equilibrium. J Sci Educ Technol. 2001;10(2):205-211. DOI: 10.1023/A:100948141.

[16] Banerjee AC. Misconceptions of students and teachers in chemical equilibrium. Int J Sci Educ. 1991;13(4):487-494. DOI: 10.1080/0950069910130411.

[17] Hackling MW, Garnett PJ. Misconceptions of chemical equilibrium. Eur J Sci Educ. 1985;7(2):205-214. DOI: 10.1080/0140528850070211.
[18] Mulford DR. An Inventory for Measuring College Students' Level of Misconceptions in First Semester Chemistry. Master of Science Thesis. Purdue University, 1996. Major Professor: William R. Robinson.
[19] Treagust DF. Development and use of diagnostic tests to evaluate students' misconceptions in science. Int J Sci Educ. 1988;10(2):159-169. DOI: 10.1080/0950069880100204.
[20] Kirbulut YD, Geban O. Using three-tier diagnostic test to assess students' misconceptions of states of matter. EURASIA J Math Sci Tech Educ. 2014;10(5):509-521. DOI: 10.12973/eurasia.2014.1128a.
[21] Hestenes D, Wells M, Swackhamer G. Force concept inventory. The Physics Teacher. 1992;30(3):141-166. DOI: 10.1119/1.2343497.
[22] D'Avanzo C. Biology concept inventories: Overview, status, and next steps. BioSci. 2008;58(11):1079-1085. DOI: 10.1641/b581111.
[23] Farand P, Tavares JR. A concept inventory for knowledge base evaluation and continuous curriculum improvement. Educat Chem Eng. 2017;21:33-39. DOI: 10.1016/j.ece.2017.07.0011749-7728.

UCZNIOWSKIE ZROZUMIENIE RÓWNOWAGI CHEMICZNEJ NA POZIOMIE SUBMIKROSKOPOWYM, MAKROSKOPOWYM I SYMBOLICZNYM

Abstrakt: Uczniom szkół średnich nie jest łatwo zrozumieć pojęcie równowagi chemicznej. W tym kontekście ważna jest informacja zwrotna dla nauczycieli, aby zoptymalizować ich pomoc dla uczniów w konstruowaniu tej koncepcji. Zaprojektowano i przetestowano zestawy specjalnie przygotowanych zadań, których rozwiązanie odzwierciedla głębokość rozumienia podstawowej koncepcji w reprezentacji makroskopowej, submikroskopowej i symbolicznej. Trudności w zrozumieniu zjawisk chemicznych i pojęć nie wynikają jedynie z istnienia tych trzech poziomów lub z ich wyjaśnienia za pomocą abstrakcyjnych pojęć, ale także z braku wzajemnego połączenia między tymi reprezentacjami. Odpowiednie wzajemne połączenie tych poziomów może prowadzić do wewnętrznego konfliktu w umysłach uczniów, a w konsekwencji do głębszego zrozumienia koncepcji lub relacji między pojęciami na wielu poziomach reprezentacji, aby je zrozumieć lub zmienić ich znaczenia. Istnieje również ścisły związek z aspektem pamięci, algorytmicznym i koncepcyjnym podejściem do rozwiązywania sytuacji edukacyjnych, który rozszerza się wymiarowo i wzmacnia potrzebę bardziej wszechstronnego opanowania przez ucznia danej koncepcji. Nauczyciel nie może oczekiwać, że uczący się bez intensywnego treningu, np. tylko obserwując makroskopową reprezentację, mogą interpretować istotę submikroskopowej reprezentacji. Dlatego te aspekty muszą być konsekwentnie włączane w model procesu poznawczego ucznia wystarczająco wcześnie, aby zastosować je w praktyce edukacyjnej bez żadnych problemów.

Słowa kluczowe: równowaga chemiczna, stała równowagi, trójkąt chemiczny, poziom zrozumienia