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THE LEVEL OF MASTERY OF THE CONCEPT OF CHEMICAL REACTION RATE BY 9TH GRADE STUDENTS

POZIOM WIEDZY NAJLEPSZYCH UCZNIÓW DZIEWIĄTEJ KLASY NA TEMAT REAKCJI CHEMICZNYCH

Abstract: In this paper, we focused on the results of research, which we have conducted to ascertain the knowledge of Slovak students who have just finished their lower secondary education concerning the topic of chemical reaction rate. The study was attended by a total of 320 15-year-old graduates of basic chemistry education belonged to several schools. Students' knowledge was found through didactic test consisted of 1 item related to clustering and several two-level tasks. The results were analyzed in terms of deeper insight into the students' understanding of the issue and students' misconceptions were also identified. The findings related to the problems connected with acquiring the concept of chemical reaction rate, especially in relation to the students' grasp the mentioned topic at submicroscopic, macroscopic and symbolic levels of representation were analyzed. We managed to investigate the students' various difficulties associated with mentioned topic. Several problems were found. Students have a problem with understanding the basic term "chemical reaction rate", relating it to bodies in motion, which they know from physics lessons and everyday life. They also have problems to distinguish and interconnect information at different levels of representation. Students often do not know which factors affect the rate of reaction and how. They do not understand the concepts of concentration and catalyst and do not distinguish the terms temperature and heat. Students' knowledge is often only formal and lacks a real conceptual understanding of the problem. Their solving of problems does not go beyond the algorithmic level of solution and they are not able to solve tasks that are not typically school-related issues.

Keywords: the chemical reaction rate, level of understanding, misconceptions, misunderstandings

Introduction

Chemical reaction rate is undoubtedly one of the most important topics in chemistry education at all levels of education. Pupils learn about basic chemical terms such as reaction rate, activation energy, factors affecting reaction rate, collision theory, catalyst, inhibitor, concentration, reactive surface area and others [1]. In addition, the knowledge that students can get from a given topic are beneficial especially in their everyday life -

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storage of food in the refrigerator, cooking food in a pressure cooker, protection of metallic materials from corrosion or production of inorganic and organic substances.

The educational system in Slovakia is set up in such a way that the students come into contact with the idea of chemical reaction rate for the first time in the 7th grade when the students are at the age of 13. They get to know the basic concepts and principles regarding the rate of chemical reactions. Once a topic has been presented, students should be able to characterize the rate of chemical reaction through a definite relationship - like that the chemical reaction rate is the change of concentration of reactants or products for a certain time. They should be able to distinguish slow and fast chemical reactions based on the visual expression of the reaction and they should also know which factors affect the reaction rate and how. A part of the lesson is also the practical activity of students associated with performing various experiments illustrating the influence of factors on the chemical reaction rate (according to state documents).

When it comes to understanding this new and relatively demanding issue, students can be confronted by various difficulties. Students may have various preconceptions, misunderstandings and misconceptions that are not in accordance with scientifically accepted knowledge and negatively affect the next steps in the learning process. These misunderstandings, misconceptions, etc. arise, e.g., in relation to the understanding of the rate of chemical reaction as a basic concept. The students already know the term "rate" before they learn about chemical reaction rate, from physics lessons or even from ordinary life experiences, and they primarily relate it to bodies in motion. Students gain understanding of this other concept of rate, which expresses the essence of chemical phenomena whose nature is not so apparent, with certain difficulties. These are manifested during the formal acquirement of the basics, during which students often indicate, e.g., the unit of chemical reaction rate as m/s or are not able to answer the question at all. The concept of the speed of movement of bodies, which was acquired earlier, is then difficult to extend to another meaning. Moreover, while the speed of a moving body can be easily demonstrated in school conditions through various examples and can also be measured in a simple way and on the other side in many cases, the rate of chemical reactions cannot even be demonstrated and its measurement would be very demanding and poorly workable.

The role of both the didactics and the teachers themselves should therefore be to identify these difficulties, preconceptions, misconceptions, etc. that have built students' knowledge structures and also to find ways to eliminate and prevent them in order to make the learning process in schools better and more effective. Being aware of students' understanding of the issue according to the model of didactic reconstruction plays an important role in the selection and structuring of the available curriculum, as well as in the selection of suitable activities in the didactic sequence. This is a way for students to conceptually master the issue and minimize the occurrence of misconceptions.

Background

Many authors [1-10] have devoted their time to studying the level of knowledge and identifying misconceptions or alternative conceptions in the field of chemical reaction rate. They have managed to reveal several misunderstandings, misconceptions that respondents had rooted in their knowledge structure, and they also revealed various difficulties related to the conceptual understanding of the mentioned issue. The authors of these studies found out that the difficulties with conceptually grasping chemical kinetics have various causes. For example, the cause of the difficulties is the limited understanding of the particulate nature of chemical reactions [11, 12]. Misunderstandings also arise because of students' misinterpretation of the terms of chemical kinetics and chemical equilibrium and thus they cannot distinguish between how far (thermodynamics) and how fast (kinetics) a chemical reaction will take place [13, 14]. Several studies have shown also large problem in defining the term "reaction rate". The reaction rate was, in many cases, understood to be the time which reactants need to produce products [1, 2]; as a collision of substances A and B at a certain time [1]; as the amount of substance that is transformed into products per unit of time at a certain temperature and concentration [3]; or as the product of reactant and product concentrations [4]. Several studies have confirmed confusions with understanding the impact of various factors on the rate of chemical reaction. In connection with temperature, difficulties in understanding of increased and decreased temperature effects on the rate of exothermic and endothermic reactions have been revealed [2, 4]. The association of increased temperature with a change in activation energy was also found [4, 5]. Data analysis has shown students' difficulties in understanding the relationships between reaction rate and concentration [2, 6, 7] and also misunderstandings about the rate of gaseous reactions being influenced by pressure or volume [8]. Several authors have discovered a problem with students' perception of the concept of a catalyst and how its presence influences the rate of reactions. According to some students, the catalyst does not react with the reactants or products [4]; or they associate its impact with increasing or decreasing the kinetic energy of the particles [4, 5], or with increasing the activation energy [5]. These misunderstandings have emerged, as it turns out, in part because the students have a problem with understanding the term "activation energy". According to the students, it is considered as e.g., the enthalpy [9]; the energy released during a reaction, or it is perceived as the kinetic energy available to the reactant molecules [2].

Research goal

One of the potential reasons for misconceptions and misunderstandings among upper secondary school students is that these misconceptions arose during the learning process of the issue at lower secondary school students. They then form the wrong foundation for the learning process at the next level of education. For this reason, we have set a goal for ourselves to find out what the students know after completing their basic chemistry education within their lower secondary education about the topic of chemical reaction rate and thus what kind of knowledge they bring to next level of education. Based on the findings, it is then possible to identify the causes of the misunderstandings and it is possible to find ways to eliminate them.

One of the causes for students' misconceptions and misunderstandings to form may be the fact that chemical content can be accessed at 3 levels of representation (macroscopic, submicroscopic and symbolic levels), but only one of them can be perceived by the senses [15]. All the levels are nevertheless equally important and complement each other [16]. Chemical content and chemical terms can be understood only when the relationships between the levels of interpretation of chemical phenomena and their differences are understood. Difficulties at one level can also cause difficulties at a different level [17]. The second objective of our research therefore consisted in determining and revealing the level of understanding of the concept of chemical reaction rate at different levels of representation and in their concurrent use.

In Slovakia, the issue of chemical kinetics is not examined. Our study therefore provides a comprehensive view on the students' understanding of the basic terms and principles in the mentioned topic.

- Firstly, it examines the range of students' knowledge relating to the phrase chemical reaction rate and thus monitors the range of the most used concepts associated with the mentioned issue.
- It monitors how students who have just completed their basic chemical education perceive the different levels of representation of chemical content, thus exploring if the students can differentiate and interconnect information from the macroscopic, symbolic and submicroscopic levels of representation.
- The research also focuses on conceptually understanding how students understand the influence of different factors on the rate of chemical reactions.
- It also tries to find out whether the students' knowledge is only formal, learned by memorization, or if the students have also captured their conceptual meaning.
- Last but not least, the research provides information to teachers, who can use the findings in the selection of teaching methods and appropriate activities for students to teach the topic.

The findings are also applicable to another didactic system as well. Therefore, research also provides information to teachers and didactics abroad, because we may encounter with the same or similar problems in other countries too.

Methodology

In the research, we used a research tool that we designed to provide better insight to the depth, breadth and character of acquirement of the concept of chemical reaction rate. A detailed description with the specification of the objectives, the full text and the basic characteristics are detailed in the study [18, 19]. In this paper, we only briefly point out the basic structure of the tool with the concretization of goals. The research tool consists of 4 blocks of items. The role of the first 3 blocks was to examine the framework of knowledge available to students at the time of submission of the research tool and to influence the real understanding of the chemical reaction rate studied in the largest fourth block.

The first block had the character of clustering. It was supposed to indicate in what typical context students from the research sample combined the concept of chemical reaction rate in microstructure around this concept.

The second block explored the students' knowledge related to the model reaction on which the students had to document their mastery of the concept of chemical reaction rate. From a chemical point of view, the whole research tool is based on the reaction of zinc with hydrochloric acid because this is a chemical reaction which is used to explain several chemical phenomena and in the Slovak didactic system is one of the model chemical reactions in several parts of the curriculum. The block consists of 2 items. The first item aimed to find out if the students knew the symbolic representation of the chemical reaction and variously indicate the dominant submicroscopic representation. The next item then examined the extent and content of the students' macroscopic representation of the chemical reaction.

The third block also consisted of 2 items. It had to explore the theoretical, abstract and formal handling of the definition of chemical reaction rate and the related expression of the size of the quantity in the respective units.

The findings from these three blocks helped to better interpret the findings from the fourth block, which identified the students' interpretation of the influence of certain factors on the rate of chemical reaction. The block consisted of 6 two-tier tasks. Gradually, they explored the conceptual handling of the influence of concentration, temperature, reactive surface area and catalyst on the rate of chemical reaction. The items should therefore show whether students' conceptual understanding of the topic of chemical reaction rate is at the level of algorithmic mastery, or it has the character of conceptual grasp. At the same time, there is a potential for identifying students' misconceptions in this area of chemistry. For better illustration, we mention at least one two-tier task from the second block of the research tool.

Task 2: In beaker A is 250 cm^3 of 30 % hydrochloric acid at room temperature and 2 g of zinc metal. Write the chemical equation of the chemical reaction that takes place in the reaction mixture in beaker A.

Task 3: Write which changes we will observe in beaker A showing that a chemical reaction is taking place.

In the students' answers, we anticipated and evaluated the accuracy and completeness of the symbolic representation of the chemical reaction of zinc and hydrochloric acid. The most anticipated answer was: $Zn + 2HCl \rightarrow ZnCl_2 + H_2$. Exceptionally, the ionic notation of the reaction could occur. In task 3, the most likely answer was the introduction of leakage bubbles of hydrogen. The observed occurrence of the formulation could be quite wide - from "bubbles" to the formula mentioned above. In the answer, students could also mention heat staining of the reaction, e.g., "heating the beaker". Similarly, less likely was also the formulation as "consumption of zinc", "decrease of zinc" and so on. Because tasks 2 and 3 formed one two-tier item, we could evaluate them through a frequency analysis. We could connect the symbolic representation of the chemical reaction with the macroscopic representation. Subsequently, we could do the interpretation of occurring or absent visualizations with respect to the accuracy of the symbolic notation of reaction.

Realization of research

The research was conducted in 2015 and 2017. The study was attended by a total of 320 15-year-old graduates of basic chemistry education within their lower secondary education. The test was administered to the students from several schools approximately 2 years after the topic was introduced. The reason for this time gap, as we mentioned above, was to investigate the students' knowledge acquired during the basic chemical education at lower secondary school and which may be used as a basis for teaching at the next level of education, upper secondary school. Students undergoing the testing had not been notified of the test and did not have the opportunity to prepare. At the beginning of the testing session, the students were told that the testing was for research purposes, and we clarified the test objectives and our research goals.

Results and discussions

Block 1 - Clustering

As we mentioned, the first block used clustering. Students had to write terms associated with the phrase "chemical reaction rate". Qualitative analysis of the students' responses showed the dominant use of term temperature (57 %, n = 182), catalyst (45%, n = 143), concentration (32 %, n = 101) and weight (24 %, n = 77) so with terms related to factors affecting the rate of chemical reaction. Nearly 6 % (n = 18) of respondents also included in the related terms volume, which can also be considered as a factor influencing rate, but is valid only for gaseous reactions. Relatively often, expressions were used related to the change of reactants to products (reactant 24 %, n = 77, product 22 %, n = 71). Terms like inhibitor (14 %, n = 44), reactive surface area (17 %, n = 52), pressure (10 %, n = 33) activation energy (6 %, n = 18), slow and fast reaction (6 %, n = 18) were represented in a significantly smaller number. Rarely also occurred terms e.g. collision theory (0.3 %, n = 1), particle collision (0.6 %, n = 2), activated complex (0.3 %, n = 1), a suitable particle orientation (0.6 %, n = 2), a rate constant (1.3 %, n = 4), definition relationship for calculating the chemical reaction rate (0.9 %, n = 3) and units in which the reaction rate is measured (0.3 %, n = 1). All of these terms were categorized as "closely related terms to the phrase chemical reaction rate" and formed 78 % (n = 956) of all offered terms (1228 terms). Students' responses also included terms that were related to the mentioned phrase in a relatively broader context (4 %, n = 51). This category consisted of more general chemical terms such as chemical bonds, chemical reaction, chemical equation, particles, molecules, substances, reaction mixture. Approximately 6 % (n = 79) of the responses were related to the term chemical reaction rate in an even wider context. These were general chemical terms such as ions, anion, cation, base, acid, metal, alkali metals, solubility, density, reactivity and thermochemistry. Some students associated the mentioned phrase with the external expression (visualization) of chemical reactions, and they therefore cited terms such as colour change, bubbling, foaming, explosion and effervescence (5 %, n = 64). Among students' responses, there were also notions not related to the rate of chemical reactions and meaningless terms - mass heat capacity, quality, mixing, reactant polarity, lost and saved time, formula of chemical reaction, strength of substance, substance ratios, fuel, accelerator, particle size, particle surface, reaction heat amount, the number of reactants, element shape, electron placement, the light, trigger, briskness and other (Fig. 1).

In terms of quantity, only one-fifth of respondents was able to write more than half of the terms closely related to the rate of chemical reactions. Most often, students were able to give 2 or 3 terms. All 8 terms were written by one student only (Fig. 2).

For the purpose of finding out the extent of students' knowledge and the most commonly used terms in relation to the rate of chemical reactions, we assigned these terms to the following categories: terms closely related to the rate of chemical reactions; terms related to the rate of chemical reactions in the broader sense; general chemical terms; visual expressions of chemical reactions; experience from laboratory exercises; and unrelated, meaningless and uncategorized terms (Fig. 1). Through these categories, we wanted to find out whether the students most likely connect the phrase "chemical reaction rate" with terms closely related to the issue, or rather to general terms that are part of general chemistry education. We also wanted to know whether students have some laboratory experience with the rate of chemical reactions, and whether they connect any experiments from school or also ordinary life with this topic.

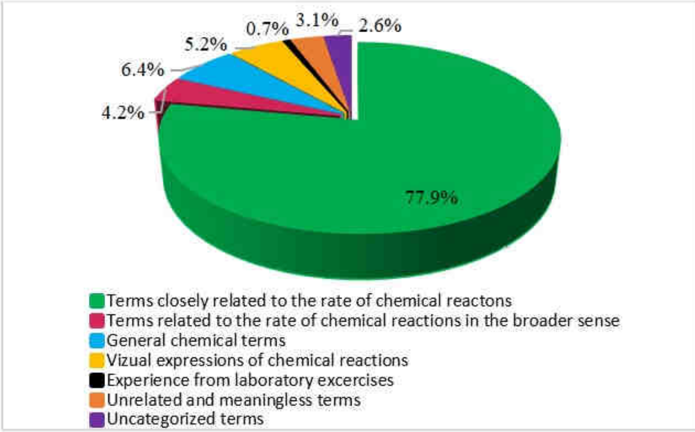

Fig. 1. The categories of terms which was listed by students in block 1 related to clustering

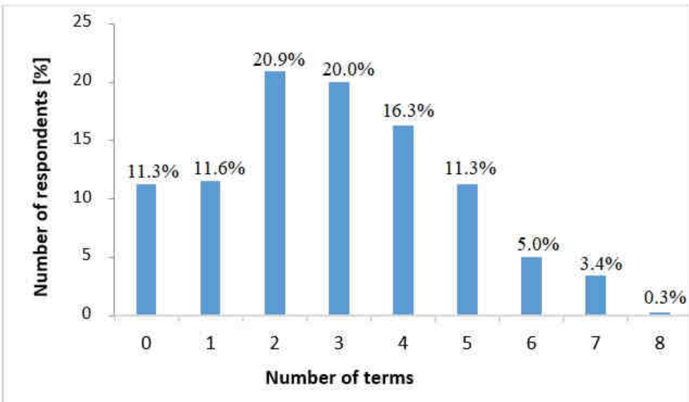

Fig. 2. The number of terms, which was listed by students in first block related to clustering

The conclusion from the analysis is that *pupils who have just completed their lower secondary education have a problem to give 8 terms closely related to chemical reaction rate. However, it follows from the nature of given terms that they know terms closely related to the rate of chemical reactions, because the most widely used terms were terms directly related to the mentioned topic*. The results also show that *the topic is associated with the students' ordinary life and the experience of laboratory exercises to a very limited extent.*

Block 2 - Understanding several levels of representation of the chemical content of the subject

In the second block, students had to write the chemical equation for the chemical reaction of hydrochloric acid with zinc. It is a reaction and its chemical equation which is used to explain different phenomena and principles during one's entire chemical education in Slovakia. In order to confirm that the chemical reaction is known by students not only at a symbolic level, they had to explain the visual expressions of this reaction. Therefore, they had to demonstrate mastery of the symbolic and macroscopic representation of the chemical reaction. Although, in our view, the task was simple, the students had difficulties with its solution. Only less than 13 % of respondents (*n* = 40) provided the correct chemical equation of the chemical reaction of hydrochloric acid with zinc. *They struggled with the chemical formulas of reactants and products* (e.g., ZnCl, Zn_2, H), or *they mentioned other reactants and products* (for instance HClO was used instead of HCl, or the product of the reaction was identified as H_2O, Cl_2, H, O_2). *They also had a problem with the quantification of the reaction* and wrote incorrect stochiometric coefficients. *Some students even had a problem with the expression (formulation) of the task*; they did not know what the chemical equation is (they wrote the formula for calculating volume). More than half of respondents (over 55 %, *n* = 177) did not even answer.

The macroscopic connections with other representations were not reported by almost half of respondents (*n* = 141). The most common answers were “bubbles of escaping gas, then dissolution of the zinc plate and finally heating of the solution, heat dissipation.” No one mentioned all three expressions of the chemical reaction at the same time. Only 6 % of students (*n* = 19) provided the correct equation and at least one correct visual expression of the chemical reaction. *The students stated that the reaction could lead to a change of colour, explosion, formation of precipitate, rusting, fuming, CO_2 leakage, leakage of bubbles of Cl_2, burning and others. Other answers included a change in charge, particle motion, formation and extinction of chemical bonds, oxidation, reduction, change of composition, pH change, concentration change etc.*, which can occur during the reaction, but we cannot see them, thus they are not one of the visual aspects of the reaction. These responses indicated that the students did not know exactly, what is the external visual expression of the reaction.

The results show students’ problems with the symbolic as well as the macroscopic level of representation of the given chemical reaction. They also have difficulties in distinguishing information which belongs to the macroscopic and submicroscopic levels of representation. Distinguishing between information belonging to the macroscopic and submicroscopic levels of representation is also problematic. Due to the fact that only 6 % of the students (*n* = 18) were able to write simultaneously the symbolic equation of the chemical reaction and at least one visual expression of the reaction, it is apparent that they are not able to interconnect knowledge from different levels of representation.

We included the mentioned task in this test mainly because the Slovak didactic system places great emphasis on the symbolic expression of chemical reactions. We aimed to point out whether the symbolic expression of chemical reactions in chemical education is so important, mainly taking into account the level of success of the students in the mentioned task. In addition, it should be noted that the test was administered in a relatively short time interval.

In the second two-tier task of this block, students had to demonstrate their understanding of the macroscopic representation of the chemical reaction. They were asked to compare the rate of reactions in beaker A and B in which zinc reacted with hydrochloric acid in a different concentration (30 % of hydrochloric acid in beaker A and 10 % of hydrochloric acid in beaker B). Subsequently the students were expected to explain how this change could be reflected in visual expression of the reaction. 85 % (*n* = 272) of the students were able to identify the impact of the concentration on the rate of chemical reaction. However, only 9 % of these respondents (*n* = 25) correctly declared how the effect of the concentration might be reflected in the visual expression of the response. In addition, only one student was able to determine more than one visual effect of the reaction. Most of the clarifications were based on the fact that the chemical reaction in beaker B was slower because it contained less concentrated (weaker) acid. Thus, the results show that *the most respondents were able to correctly identify the variable causing a change in the rate of chemical reaction in beaker B with respect to beaker A, but they could not support their claim by writing the macroscopic expression and they remained at the submicroscopic and formal levels of representation*.

The overall level of success of this two-tier task again indicates that students *are not able to connect knowledge from different levels of representation*; it also reflects the level of education in our schools and the failure to teach them to establish these connections.

Block 3 - Deduction of the definition relation and units for chemical reaction rate

The next block consisted of tasks in which students were expected to demonstrate their knowledge about the nature of a chemical reaction rate by writing a definition relation, especially at the level of memory reproduction; they were subsequently supposed to demonstrate the ability to apply their understanding of this relation in the deduction of the unit for the chemical reaction rate. Only 5 % of the students (n = 17) were able to write a correct definition relation and only 3 % (n = 10) were able to deduce the units in which the chemical reaction rate is measured. Only 2 % of respondents (n = 7) were able to write at the same time the correct definition relation for the calculation of the chemical reaction rates and the units in which the chemical reaction rate can be measured. Most of the students did not answer the questions.

The students' answers revealed their problem with the understanding of the relation for the calculation of the chemical reaction rate. *They had difficulties in determining the units used in Slovakia*. Instead of marking v, they used the markings t (time), K (equilibrium constant), n (amount of substance), or they used no markings. *The relation for the calculation of the chemical reaction rate was often replaced by a relation for an equilibrium constant calculation, using the Pythagorean Theorem for the calculation of the length of sides in a right triangle or by the equation of the status for the ideal gas. Students confused the relation for the calculation of the chemical reaction rate with the chemical equation. They also incorrectly thought that the chemical reaction rate was about a change in volume, weight, or area over a certain period of time.* This was also confirmed by units like mg/s, g/s or ml/s that appeared in the students' answers to the question regarding the units we use to measure the rate of chemical reactions. In connection with the erroneous indication of quantity, it was shown that *the students think the reaction rate is measured in units of time* (seconds, minutes, hours), and also that *the reaction rate is often confused with the amount of matter, as mol*. The units m/s and km/s also confirmed the *students' confusion of the chemical reaction rate with the velocity of the moving body* known from physics and everyday life.

The results show that *students are not able to define the relation for calculating the chemical reaction rate or even name the units in which the reaction rate is measured.* The level of success of these two tasks highlights the considerable formality of their knowledge. The low percentage of success in this two-tier task showed that the information which students commit to memory only on the basis of memory reproduction, without understanding, was not permanent; they forgot it and were not able to use and work with it. Again, this is a question for the Slovak educational system, focusing on factual knowledge whether the orientation towards this type of knowledge is the right way to achieve natural literacy due to the duration of students' knowledge.

Block 4 - Understanding the influence of factors affecting the rate of chemical reactions

In the last, largest and centrobaric block, we examined the students' view on the factors affected the rate of chemical reactions. The students were asked to demonstrate their understanding of how the rate of the chemical reaction of hydrochloric acid with zinc affected:

- the increased temperature (the students had to compare the rate of the reaction at room temperature and at 80 °C),
- the presence of a catalyst or an inhibitor (the students had to compare the rate of the mentioned reaction with urea and without urea),
- the greater volume of acid (the role of students was to compare the chemical reaction rate of 250 or 500 $cm^3$of 30 % HCl),
- the surface area of the reactants caused by a larger amount of zinc metal plate (students had to compare the chemical reaction rate when HCl reacted to 2 g of zinc and when it reacted to 10 g of zinc),
- the surface area of the reactants caused by different zinc forms (the students had to compare the rate of the chemical reaction when HCl reacted to 2 g of zinc like plate or like powder).

This block consisted of two-tier tasks. While in the first part the students were expected to determine how the factor influences the rate of the chemical reaction (e.g., no change, increase, decrease, cannot be determined), in the second part they were asked to explain their answer, to confirm their understanding of the concept of the chemical reaction rate. The students had to prove that they had a real conceptual grasp of the influence of factors on the rate of chemical reaction or just formal knowledge learned by memorizing is dominant.

Temperature

Data analysis showed that students are most familiar with how the chemical reaction rate influences increasing temperature. In the first part of the two-tier task devoted to identifying the effect of temperature on the rate of chemical reactions, the students achieved a success rate of 78 % (n = 249). They wrote that higher temperatures caused an acceleration of the chemical reaction. However, they were not so successful in explaining their answer. Most of the respondents explained their responses by stating that the reaction rate was greater because the temperature increased. Therefore, with respect to these students, we can assume their knowledge is based on the memorizing of the theory. The fact that the acceleration of the chemical reaction was caused by the increasing kinetic energy of the particles, and thus the greater the probability of effective collision was mentioned by only 17 % (n = 41) of the students. We assume they had a real conceptual grasp of the issue. Others answered that the reaction rate was higher because *the heat acts as a catalyst.* This revealed *students' misinterpretation of terms heat and temperature and misunderstanding of the definition of the catalyst and how it works*. In one of the explanations for the faster reaction at a higher temperature, a student wrote that *a soluble compound dissolved faster at a higher temperature. The students are mistaken about the* *processes of dissolution and chemical reaction.* The rate of a chemical reaction would be the same at room temperature and at 80 °C was claimed by 6 % (*n* = 20) of the students. The reason is that *temperature does not affect the reaction rate.* According some students, *the reaction of hydrochloric acid with zinc was an exothermic reaction and, therefore temperature had no effect on the reaction rate.* Approximately 4 % of respondents (*n* = 14) claimed that *an increase in temperature causes a decrease in the rate of chemical reaction.* Some also stated that the rate of chemical reaction cannot be determined (4 % of students, *n* = 14).

The results show that students know that increased temperature causes an acceleration of chemical reactions, especially at the level of memory reproduction, but they cannot explain the cause of this change.

The surface area of the reactants caused by different zinc forms (metal plate/powder)

The temperature was followed by the factor - reaction surface area of the reactant. The students were supposed to identify the impact of this factor in the task when comparing the reaction rate of hydrochloric acid with zinc in the form of a metal plate and then in the form of a powder. Nearly 66 % (*n* = 210) of the students correctly determined that the reaction rate of hydrochloric acid with zinc was greater in the form of a powder than in the form of a metal plate. It was a typical school example used in teaching the impact of this factor; therefore, we cannot be satisfied with the result. In addition, up to 35 % (*n* = 74) of the students who gave the correct answer in the first part of the task stated only that zinc powder was more reactive than a zinc plate. Only 36 % (*n* = 76) of respondents wrote that the change in rate was caused by an increase in the surface area of the reactant, and only one student determined that the zinc powder had a larger surface area and hence more effective collisions between zinc and acid could occur. *Some students stated that zinc powder had smaller particles that react more quickly*. Nearly 17 % (*n* = 53) claimed that *the reaction rate did not depend on the form of zinc*, but that it was important that in both cases the same amounts of zinc with the same concentration of acid reacted at the same temperature. Nearly 6 % (*n* = 19) of students thought that *the reaction with the zinc powder would be slower because the zinc metal plate had a larger surface area.*

The analysis therefore shows that it is difficult for the students to determine how the rate of chemical reactions is influenced by the increasing of the reactants' surface area.

Volume of acid

A two-tier task followed in which the students were expected to determine the effect of an increased volume of hydrochloric acid with the same concentration on the rate of chemical reaction with zinc. The level of success of students in the first part of the task was 46 % (*n* = 146). Therefore, students had more difficulties in identifying the impact of this factor. The low success rate was also due to the fact that it was not a typical school question, considering that volume is not mentioned when teaching about the factors affecting the rate of chemical reactions. Since volume is not usually mentioned in the teaching process as a factor influencing the chemical rate, we could observe an answer stating that the reactions in both cases would run equally fast because volume does not affect the reaction rate (40 %, *n* = 58). According to another response, the reaction rate will be the same, because in both cases zinc was paired with the same concentration of hydrochloric acid (47 %, *n* = 70). Another 0.6 % of respondents (*n* = 2) stated that the reaction area was the same despite the increased volume. Nearly one third of the students said that *if the volume of acid is greater, the reaction will take place faster*. According to one of the explanations, *more particles are present in the larger volume and they can react with the zinc*; another student stated that *the concentration of acid increased with the increase in volume*. Thus, *students have difficulty in understanding the composition of solutions, they have problems in understanding the concept of concentration and mass fraction. They also thought that the probability of a collision of zinc particles increased if the volume of acid was increased.* Another 22 % (n = 71) of students wrote that the reaction *in a larger volume of acid is slower because the particles are further away from each other and it takes them more time to react together.* The problem of understanding the composition of solutions was identified again because the students explained the lower reaction rate in a larger volume due to the fact that the acid was less concentrated, more diluted, and thus its effect was lower. The results indicate that students have difficulty in determining the key variable, in this case, the concentration.

The presence of a catalyst or an inhibitor

The level of success of the students in the next two-tier task was even lower. In the first part it was only 43 % (n = 138). The students had to decide how the rate of reaction of zinc with hydrochloric acid would be influenced by the addition of urea. The biggest problem was that respondents did not recognize the chemical properties of urea and did not know whether it was acting as an inhibitor. It is striking that only 30 % (n = 41) of the students who answered the first part correctly were able to justify their responses. It should also be noted that the explanation was like urea acts as an inhibitor, slowing down the reaction. Again, we only encountered an explanation on the formal level of the theory. Not even one considered the increase in the activation energy and, therefore, a smaller number of particles that could interact with each other. We also found claims that *adding urea leads to the dilution of the solution and weakens the effect, i.e., reduces the acid concentration*. Some students wrote that *urea acts as a catalyst, reducing the rate of reaction*. Again, we can see that *students do not have a straightforward concept of catalyst*. Nearly 22 % (n = 69) of students stated that *adding urea accelerates the reaction as it acts as a catalyst*. The remaining 32 % (n = 101) of students did not respond at all or wrote that *the rate could not be determined*. The results indicate that they have a problem in determining how urea affects chemical reaction rates and they have not learnt the terms catalysts and inhibitors.

The surface area of the reactants caused by a larger amount of zinc metal plate

The greatest difficulty was revealed in the two-tier task in which the students had to determine the impact of a larger amount of zinc plate on the chemical reaction rate (the students were supposed to compare the reaction rate of 250 cm^3 of 30 % HCl with 2 g of zinc metal plate or the same amount of 30 % HCl with 10 g of metal zinc plate). It was again an example of how the reaction surface area influences the chemical reaction rate, but it was not a typical school example used to teach this factor as the case mentioned above. Thus, the students often did not realize that the reactive surface area of the reactant increased with the increased weight of the reactant (assuming the same thickness of the plate). The level of success was only 33 % (n = 105). Almost half of the group of students (48 %, n = 50) who responded correctly in the first part of the two-tier task explained their response by simply saying that the reaction rate is greater because there is more zinc in the beaker. Again, we cannot talk about the actual conceptual grasp of these issues by these students. Another 12 % (n = 13) of students mentioned the size of the reaction surface area, and only 2 % (*n* = 2) answered that a larger amount of zinc had more particles which could react with the acid and thus increase the probability of an effective collision of these particles. According to another response, the reaction was faster because *zinc acts as a catalyst*. Again*, there was a problem with understanding what is and how the catalyst works*. With respect to misconceptions, we have found out that 49 % (*n* = 157) of the students think that *with more zinc the rate of response decreases due to the fact that a larger amount of reactant reacts or dissolves longer and hence the reaction rate is lower*. The results indicate that the students have a problem in determining that the reactive surface area of the reactant can be increased with the increasing weight of the reactant, and thus the chemical reaction accelerates.

Table 1

Students' level of success in two-tier items

Two-tier tasks	**Number of students (x), who provided the correct answer in the first part of the task [%] (*n* = 320 students)**	**Number of students who stated the correct justification [%] (*n* = *x*)**	**Number of students who provided reasoning at the theoretic level [%] (*n* = *x*)**	**Number of students who did not respond at all [%] (*n* = 320 students)**
Symbolic equation of chemical reaction	12.5	47.5	-	33.1
Concentration effect	85.0	9.2	49.0	0.9
A definition of relation for the calculation of the reaction rate	5.3	41.0	-	62.0
Temperature effect	78.0	16.5	63.1	7.2
Surface area effect (zinc form)	65.6	33.8	37.6	7.8
Influence of the volume of acid	45.6	19.2	55.5	3.1
The effect of the inhibitor	43.1	0	29.7	16.3
Surface area impact (zinc weight)	32.8	15.2	47.6	5.6

Conclusions

Based on the goals we set, we found out that students have difficulties regarding chemical reaction rates after completing basic chemistry education. They have a problem in defining 8 closely related terms to the phrase "chemical reaction rate." However, most of these used terms are related to this category of terms. We also found out that the subject of the rate of chemical reactions is associated with everyday life and the experience from laboratory exercises to a very limited extent. When analysing the results, we discovered problems with the students' understanding of the basic term "reaction rate". They connect it with the movement of the body as a topic from physics, which is taught before chemical reaction rate, and from ordinary life. Some students also perceive the rate of chemical reactions as a time interval during which the chemical reaction takes place. Based on their responses, we found out students' problem with distinguishing between information belonging to macroscopic and submicroscopic levels of representation. They also have difficulties with the symbolic level of representation. It appears that they are not able to distinguish and connect knowledge from several levels of representation. Research results also showed difficulties with the factors influencing the rate of chemical reaction. In many cases, the students know how the factors influencing the chemical reaction rate (temperature, concentration, reactive surface area) affect the chemical reaction rate (decrease, increase), but they do not explain the influence of these factors at submicroscopic level of representation through collision theory. Only algorithmic level of solution of tasks related to factors affecting the chemical reaction rate was identified. There was revealed formal knowledge of students without real understanding of the problem. It was also shown that students are not able to solve tasks that are not typically school related issues. Students do not know whether the chemical reaction rate affects the volume of solution, they do not take into account the fact that by increasing the weight of solid reactant of the same thickness, the reactive surface area of the reactant increases, and they have difficulty in understanding that the rate of reaction also depends on the form of the reactant, and so the reaction is faster with smaller pieces of reactant. By stating that temperature or zinc worked like catalyst, or catalyst reducing the rate of reaction, we can claim that students have problems in understanding the concepts of catalyst and inhibitor. Also, problems with understanding the concept of concentration was identified. Students think that concentration of solution changes with the change in volume. The problems in understanding the concepts of temperature/heat and chemical reaction/dissolution was discovered. Problems are also encountered in questions concerning the reproduction of factual knowledge, despite the fact that they are emphasized in the curricula at Slovak schools. Here is the question, if it would not be necessary to change this system. The students' failure in this test is therefore seen in the failure of our didactic system. The findings of research could help us to bring about a change in basic chemistry education and also in the didactic reconstruction of the topic of the rate of chemical reactions for 7^{th} grade students. Our research findings could also help teachers and pedagogues from other countries because they can be applied to other didactics systems in which the same or similar problems in teaching the mentioned topic may be found.

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POZIOM WIEDZY NAJLEPSZYCH UCZNIÓW DZIEWIĄTEJ KLASY NA TEMAT REAKCJI CHEMICZNYCH

Abstrakt: Opisano wyniki badań dotyczących wiedzy słowackich absolwentów gimnazjum na temat szybkości reakcji chemicznych. W badaniu wzięło udział łącznie 320 15-letnich absolwentów kilku szkół, którzy ukończyli kurs podstawowej edukacji chemicznej. Wiedza uczniów została oceniona poprzez test dydaktyczny składający się z jednej pozycji związanej z tworzeniem klastrów i kilkoma zadaniami dwupoziomowymi. Wyniki analizowano pod kątem głębszego zaangażowania uczniów w zrozumienie problemu i zidentyfikowano błędne przekonania uczniów. Omówiono wyniki związane z problemami rozumienia pojęcia szybkości reakcji chemicznych, zwłaszcza w odniesieniu do opanowania przez uczniów wspomnianego tematu na submikroskopowych, makroskopowych i symbolicznych poziomach reprezentacji. Udało się określić różne rodzaje trudności uczniów związane z tym tematem. W związku z tym znaleziono kilka problemów. Uczniowie mają kłopot ze zrozumieniem podstawowego pojęcia „szybkość reakcji chemicznych", odnosząc je do poruszających się ciał, które znają z lekcji fizyki i życia codziennego. Mają także problemy z rozróżnianiem i łączeniem informacji na różnych poziomach reprezentacji. Uczniowie często nie wiedzą, które czynniki i w jaki sposób wpływają na szybkość reakcji. Nie rozumieją także pojęć stężenie i katalizator oraz nie rozróżniają terminów temperatura i ciepło. Wiedza absolwentów jest często tylko formalna i nie zawiera prawdziwego konceptualnego zrozumienia problemu. Ich sposób rozwiązywania problemów nie wykracza poza poziom algorytmiczny, nie są w stanie rozwiązać zadań, które nie są typowo szkolne.

Słowa kluczowe: szybkość reakcji chemicznych, poziom zrozumienia, błędne koncepcje, niezrozumienie