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The effects of online learning about the Brønsted–Lowry theory of acids and bases in the first grade of grammar school during the COVID-19 pandemic

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Abstract: The aim of this paper was to examine the effects of the application of online material on the Brønsted-Lowry theory of acids and bases on the active construction of knowledge in first-grade grammar school students during the COVID-19 pandemic. The online material was designed to enable students: a) to learn the teaching material in smaller parts; b) to assess the acquired knowledge after each part of the teaching material; c) to progress through the lesson at their own pace; d) to visualise and interrelate the macroscopic, submicroscopic and symbolic representations of the contents about acids and bases by using a video recording and illustrations; e) to re-examine the accuracy of the given answers. The research sample consisted of 122 first-grade grammar school students, who learnt about the Brønsted–Lowry theory for the first time. The instruments used in this research study were two tests (a pre-test and a post-test), the validity of which was examined by two university professors and two grammar school chemistry teachers. The applied approach enabled the active construction of knowledge in the majority of students, while it provided the teachers with an insight into the progress and outcomes of the process.

Keywords: online education; first grade of grammar school; acids and bases; COVID-19.

INTRODUCTION

The COVID-19 pandemic has caused major changes in instructional strategies by introducing a considerable amount of online instruction. The popularity of online courses had been increasing even before the pandemic, mainly at higher levels of education, due to greater availability of such instruction, its flexibility and the fact that it enables students to study at their own pace.[1]

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A comparison of the effects achieved by classroom education and the ones achieved by distance education was the subject of numerous research studies in the previous decades. In a meta-analysis which included 355 research reports and papers published in the period from 1928 to 1998 there were no significant differences between the achievements of the participants taught using traditional classroom instruction and those taught using distance instruction by means of various technologies.[2] Similarly, such differences were not found in some subsequent meta-analyses.[3,4] Furthermore, a significant difference in the participants' level of satisfaction with the quality of teaching was not found.[5,6] Even though these research studies did not show a significant difference in the outcomes achieved by distance and classroom education, a study focusing on the differences between some programmes showed that their outcomes could vary depending on a series of pedagogical and technological factors.[7] In some meta-analyses, somewhat better effects of distance education in comparison with traditional classroom education were determined, but it was pointed out that careful interpretation of the average effect was necessary due to various formats of distance learning.[8,9]

It was established that low-confidence students felt better during online education and that they experienced greater freedom and less pressure in that kind of environment, while the impression of anonymity encouraged them to be more active, ask questions and complete the assignments.[10] However, students did not always assess positively reduced participation of teachers in online courses due to the impression that they had to "teach themselves". As a result, they chose online instruction for easier subjects, while they chose traditional classroom instruction for more difficult subjects.[11]

Flexibility turned out to be a desirable characteristic of online education to many students. However, even though students appreciated the applied format of asynchronous online learning, the ability to access materials at their own pace, at a time and place that suits them, some of them stated that they preferred regular real-time engagement and feedback information they could get in that way, *i.e.*, synchronous instruction in which the teacher and students simultaneously deal with the content of the course through interaction. These students believed that, in various uncertain circumstances, the real-time engagement offered them greater security and consequently greater motivation to learn.[12] A lack of direct teacher–student contact in online instruction and different kind of communication on various online platforms presented a great change for both students and teachers.[10] Therefore, in order to make distance learning more effective, synchronous online instruction and communication are recommended, as well as the use of interactive technologies, and teacher training in planning and realization of online teaching.[13,14]

Programs and applications which support synchronous and asynchronous online learning are constantly improved, enabling and supporting the student interaction with the course content, the teacher and other students.[6,15,16] However, in order to use these applications and to enable the access to various educational resources, certain technical conditions have to be met, primarily Internet access and the availability of devices. Apart from providing the technical conditions, another important issue is the environment in which students can study, *i.e.*, finding a peaceful place in their place of living where they can take the lessons and participate in the activities. In traditional instruction, this environment is provided in the classroom by the teacher, who manages the process of teaching and learning in the school environment.

Teachers' concern regarding online instruction relates to cheating while doing the assignments, *i.e.*, copying, which can occur when students are not under teachers' direct supervision. A solution to this problem might be writing some new and specific questions and problems, which students could solve by using the information found on the Internet, but the information should provide only partial help with formulating their answers. In this way, students are more engaged, they are less inclined to cheat/copy and better effects of learning are achieved.[16]

Research studies which focused on the degree to which online instruction and chemistry learning enabled effective formation of new knowledge and skills compared to traditional instruction also included the skills necessary for experimental work.[17,18] Learning about the chemistry laboratory through distance learning can be a virtual experience through some platforms, but it can also be a hands-on experience, which can be achieved by using mail-order laboratory kits.[19]

While some students are more engaged within online instruction, others tend to exclude themselves for various reasons, which raises the question of how to monitor students' engagement and progress in the online environment. This can be achieved by using discussion platforms, organising a test or a quiz, which can be graded or ungraded, organising a self-quiz and some other activities of formative assessment in order to determine when a student needs some additional support and assistance.[12] Involving students in solving online homework also can contribute to their better achievement.[20]

Engaging students in activities during the COVID-19 pandemic presented a challenge for teachers, particularly in the situation of a sudden switch to online instruction. This paper presents an attempt to find a way to improve student interaction with the course content in order to enable active knowledge construction in the online environment.

EXPERIMENTAL

The aim of this research study was to examine the effects of the application of online material on the Brønsted–Lowry theory of acids and bases on the active construction of knowledge in first-grade grammar school students during the COVID-19 pandemic. Based on the established aim the following research questions were formulated:

1. To what extent do students construct the meaning of the concepts related to the Brønsted–Lowry theory of acids and bases using the online learning material?
2. What kind of interaction do students have with the contents of the online material on the Brønsted–Lowry theory of acids and bases?

The Brønsted–Lowry theory of acids and bases was chosen as the teaching content in this research study since it was studied for the first time in the first grade of grammar school. Students' problems with learning the concepts of acids and bases had been pointed out by some research studies,[21] and the cause of the problems with understanding these concepts had also been observed within the explanations in some textbooks.[22]

The research study was conducted in the online environment, in line with the recommended organisation of teaching in Serbia in April 2021. The sample consisted of 122 first-grade grammar school students (14–15 years old). Prior to the beginning of the research study, the consent for the participation in the research study based on the presented aim and the method of research realisation had been obtained from the school, and a contract between the school and the University of Belgrade – the Faculty of Chemistry had been concluded. The students' participation in the research study was voluntary, and their achievement in the tests did not influence their chemistry grade. Through online communication, the aim of the research study and the expected activities were explained to the students. The links to the online material and tests, prepared in the Google Forms application, were forwarded to the school's chemistry teacher, who sent them to the students to work at the time when their chemistry class was supposed to be according to their school timetable. That was the first time they studied Brønsted–Lowry theory of acids and bases (according to the chemistry curriculum, the students in the sample had previously studied the Arrhenius theory of acids and bases in the seventh grade of primary school, at the age of 13). At the beginning of their work, students did a pre-test which tested their knowledge of acids and bases acquired at primary school. Afterwards they learnt about the Brønsted–Lowry theory of acids and bases using the online material. At the end they did a post-test which examined the knowledge gained by working with the online material.

The online material on the Brønsted–Lowry theory of acids and bases was prepared in such a way as to enable students: a) to learn the teaching material in smaller parts; b) to assess the acquired knowledge after each part of the teaching material; c) to progress through the lesson at their own pace; d) to visualise and interrelate the macroscopic, submicroscopic and symbolic representations of the contents about acids and bases by using a video recording and illustrations; e) to re-examine the accuracy of the answers they produced. The teaching material was divided into seven parts. Each part of the lesson was followed by items which checked the student achievement in learning that part of the lesson and student interaction with the contents. Students were also expected to select the information based on which they had formulated their answer to the item, which encouraged them to re-examine the given answer. Based on the students' answers the teacher was able to observe within which part they had had a problem with understanding the contents, which pieces of information they had selected as relevant to formulating the answers and to plan subsequent additional support accordingly. The text of the online material, the illustrations, the video recording and the items were prepared based on the corresponding outcomes defined within the chemistry curriculum for the first grade of grammar school. When formulating the textual part of each segment, special attention was devoted to the length of sentences, the use of terms which were familiar to students and the explanation of the meaning of new terms, the number of concepts and clear definition of the new terms.

A pre-test and a post-test were designed according to the research aim and research questions. The pre-test consisted of five open-ended items. In the first and second item students were expected to provide the definitions of acids and bases according to the Arrhenius theory, which they had studied at primary school. In the third and fourth item, they were to provide names and formulae of two acids and two bases respectively, while in the fifth item they were expected to write the term used for a chemical reaction between acids and bases.

The post-test also consisted of five items, three open-ended and two multiple-choice items. In the first and second item students were expected to provide the definitions of acids and bases according to the Brønsted–Lowry theory of acids and bases, which they had studied using the online material. The third item tested students' understanding of the limitations of the Arrhenius theory in explaining acid–base properties of substances. In the fourth item they were to identify amphoteric species among the given examples, while in the fifth item they were supposed to identify conjugate acid-base pairs.

The validity of the instruments was assessed by two university professors of the Department of Chemical Education at the University of Belgrade – the Faculty of Chemistry and two grammar school chemistry teachers. The reliability of the tests was examined by means of Cronbach's Alpha coefficient. The value of Cronbach's Alpha coefficient in the pre-test amounts to 0.688, and in the post-test to 0.600, which indicates a lower level of internal consistency of the instruments. This could be related to the specific circumstances in which the research study was conducted and the newer way of testing students at that time.

To monitor students' voluntary interaction with the content of the online material the Google Forms application had been set in such a way that students had to provide answers only to the items of the post-test.

RESULTS AND DISCUSSION

The characteristics of the distribution of the pre- and post-test scores (the minimum and maximum number of points achieved, the arithmetic mean, the standard deviation, the *skewness* and *kurtosis* values) are presented in Table I. The *skewness* and *kurtosis* values are within ±1 range, so the distribution of the scores in the pre- and post-testing can be considered to be normal.

TABLE I. The characteristics of the distribution of the pre- and post-test scores (the maximum number of points is 7 in the pre-test and 5 in the post-test)

Test	*N*	*Min*	*Max*	*M*	*SD*	*Skewness*	*Kurtosis*
Pre-test	122	0	7	4.98	1.52	–0.913	0.852
Post-test	122	0	5	3.63	1.25	–0.852	0.354

Table II shows the number and percentage of students who provided correct and incorrect answers to the pre-test requirements.

A larger number of students gave a correct definition of acids compared to bases according to the Arrhenius theory. Furthermore, a larger number of students provided the names and formulae of acids in comparison to bases. Students' answers showed that, even though over 40 % of them could not provide a definition of acids and bases, they were familiar with the formulae and names of some acids and bases. Also, a high percentage of students were familiar with the term neutralization.

TABLE II. The frequency of correct and incorrect answers to the pre-test items

Item	Correct answers		Incorrect answers	
	N	%	*N*	%
1. Definition of acids	73	59.8	49	40.2
2. Definition of bases	61	50.0	59	48.4
3. Names and formulae of two acids	110	90.2	8	6.6
4. Names and formulae of two bases	72	59.0	42.5	34.8
5. Neutralisation	109	89.3	8	6.6

The second research question related to student interaction with the contents of the online material on the Brønsted–Lowry theory of acids and bases. It can be examined based on their answers to the items following each part of the online material. The frequencies of students' correct and incorrect answers to these items are given below (Table III).

Within the first part of the online material, students had an opportunity to recall the definitions of acids and bases according to the Arrhenius theory. In the item which followed, they were expected to identify acids and bases based on the given chemical formulae as well as the ions in the aqueous solution due to which those compounds exhibit acidic or base properties. The percentage of correct answers to eight such requirements was high (73–96 %), particularly for the formulae of inorganic bases and inorganic acids, while it was somewhat lower for the formula of the organic acid. In addition to this, it was observed that a smaller number of students (between three and nine), who had correctly identified inorganic compounds, did not relate the ion in the solution to the acid–base properties of that solution. Even though they identified an acid or a base based on its formula, these students had not understood the information given in the first part of the online material on the electrolytic dissociation and ions due to which solutions exhibit acidic or basic properties, *i.e.*, they had not interrelated the symbolic and submicroscopic level. The highest percentage of incorrect answers (20.5 %) related to the example of an organic acid (methanoic acid), while the percentage of incorrect answers for other examples was below 10 %.

In order to examine the student interaction with the content and the comprehension of the text they had read, Table IV presents the frequencies of students' assessments as to which pieces of information in the first part of the material were relevant to formulating the answers. They could choose more than one piece of information. This item referred the students back to the text in the first part of the online material and offered them an opportunity to re-examine the answer they produced.

TABLE III. The frequencies of correct and incorrect answers to the items in the online material on the Brønsted–Lowry theory of acids and bases

Items following each part of the online material – the description of the requirements	Correct answers		Incorrect answers	
	N	%	*N*	%
1a. Identifying to which class the compound KOH belongs[a]	111	91.0	7	5.7
1b. Identifying the ions due to which KOH solution has basic properties	98	80.3	7	5.7
1c. Identifying to which class the compound HNO_3 belongs	117	95.9	3	2.4
1d. Identifying the ions due to which HNO_3 has acidic properties	98	80.3	3	2.4
1e. Identifying to which class the compound $Mg(OH)_2$ belongs	105	86.1	7	5.7
1f. Identifying the ions due to which $Mg(OH)_2$ solution has basic properties	97	79.5	10	8.2
1d. Identifying to which class the compound HCOOH belongs	89	73.0	16	13.1
1f. Identifying the ions due to which HCOOH solution has acidic properties	91	74.6	25	20.5
2a. Recognising reaction products	99	81.1	22	18.0
2b. Describing observations regarding the chemical reaction	9	7.4	72	59.0
3a. Identification of acids according to the Brønsted-Lowry theory of acids and bases	61	50.0	59	48.4
3b. Identification of bases according to the Brønsted-Lowry theory of acids and bases	72	59.0	49	40.2
4a. Recognising ammonia as a proton acceptor	110	90.2	12	9.8
4b. Recognising hydrogen chloride as a proton donor	109	89.3	13	10.7
5a. Identification of the conjugate base	87	71.3	34	27.9
5b. Identification of the conjugate acid	85	69.7	35	28.7
6. Explaining the acidic properties of HCl according to the two theories	36	29.5[b]	54	44.3
7. Explaining the basic properties of NH_3 according to the two theories	11	9.0[b]	87	71.3

[a]Within item 1 students were expected to identify acids and bases according to the Arrhenius theory; [b]the percentage of correct explanations according to both theories. There were also partially correct answers to the items following the sixth and seventh part of the online material (32 % of students provided a correct explanation for item 6 according to the Arrhenius theory and 54 % according to the Brønsted–Lowry theory of acids and bases, while 10.7 % of students provided a correct answers for item 7 according to the Arrhenius theory and 37.7 % according to the Brønsted–Lowry theory of acids and bases)

The majority of students based their answers on the definitions of acids and bases in the text, while less than half of the students also based their answers on the examples of the dissociation of acid and base, given at the symbolic level. The higher percentage of students who marked the pieces of information relevant to formulating the answers was in line with the percentages of correct answers to the first item. However, less than 11 % of students assessed as relevant some pieces of information based on which they could not provide answers to the first item. These students required some additional support in order to understand the information given in the text and at the symbolic level. It is important that chemistry teachers have this in mind when planning the material for learning in the online environment.

TABLE IV. The frequencies of the pieces of information from the first part of the online material on the Brønsted–Lowry theory of acids and bases used to formulate the answer

Information	*N*	%
The first theory which described acids and bases was the theory of electrolytic dissociation. The theory was proposed by a Swedish chemist, Svante August Arrhenius (1859–1927) in 1887.	10	8.2
According to the theory of electrolytic dissociation, acids are substances which dissociate in water to give hydrogen ions H^+ as positive ions.	105	86.1
For example: $HCl \xrightarrow{H_2O} H^+ + Cl^-$	51	41.8
Hydroxides (bases) are substances which dissociate in water to produce hydroxide ions OH^- as negative ions.	96	78.7
For example: $NaOH \xrightarrow{H_2O} Na^+ + OH^-$	51	41.8
The Arrhenius theory of electrolytic dissociation can explain acids and bases to a limited extent since it refers only to aqueous solutions.	8	6.6
It can be used to explain the formation of a salt when aqueous solutions of an acid and a base are mixed (for example, when hydrochloric acid and the aqueous solution of sodium hydroxide react, water and sodium chloride, a salt dissolved in water, are produced).	13	10.6

In the second part of the online material, information was conveyed to students using a video recording which showed a reaction between hydrogen chloride and ammonia and a text which contained an explanation regarding the formation of NH_4^+, *i.e.*, the formation of ammonium chloride. Students' understanding of the information explained through the video and the text was checked by a multiple-choice item in which students were expected to identify symbolically represented ions formed in the reaction and by an open-ended item, in which they were expected to describe what in the experiment indicated that hydrogen chloride and ammonia reacted. The percentage of correct answers to the multiple-choice item was high (81 %). However, out of the two thirds of the students who answered the open-ended item, only 7 % correctly described the indicator of the chemical reaction in the experiment they had observed. This indicates that a large number of students did not relate the information from the text regarding the submicroscopic level of the chemical reaction between hydrogen chloride and ammonia to the information from the video, in which the reaction is presented at the macroscopic level. Therefore, students need some additional support with collecting data on the properties and changes of substances by observation, interpreting the observations at the submicroscopic level and relating them to the symbolic representations of substances and their changes.

In the third part of the online material, it was explained how the limitations of the Arrhenius theory in defining acids and bases can be overcome with the help of the Brønsted–Lowry theory of acids and bases and new definitions of these concepts were given. In the item which followed students were expected to identify among the options offered which species, represented at the symbolic level, can act as acids and which as bases. Half of the students correctly identified the examples of acids, while slightly more than half of them correctly identified the examples of bases. The fact that a charged particle such as, for example the NH_4^+ ion, can act as an acid was new to the students, which explains a somewhat lower percentage of correct answers to this item. The frequencies of students' answers as to the pieces of information from the text based on which they answered the items are presented in Table V (they could choose more than one piece of information).

TABLE V. The frequencies of the pieces of information from the third part of the online material on the Brønsted–Lowry theory of acids and bases used for formulating answers

Information	*N*	%
The Brønsted–Lowry theory of acids and bases is broader than the theory of electrolytic dissociation and also provides explanations for acid-base properties of substances in non-aqueous solutions.	6	4.9
The theory was proposed independently by two scientists in 1923, the Danish scientist Johannes Brønsted (1879–1947) and the English scientist Thomas Lowry (1874–1936).	9	7.4
According to the Brønsted–Lowry theory of acids and bases acids donate H^+ (it means that they are proton donors) to other ions or molecules, and bases accept H^+ (it means that they are proton acceptors).	108	88.5
A substance can act as an acid (HA) and donate protons, only if there is another substance which acts as a base (B) and accepts protons.	38	31.1
This can be represented by the following general equation: $HA + B \rightleftharpoons BH^+ + A^-$	47	38.5

The majority of students based their answers regarding the third part of the online material on the definitions of acids and bases according to the Brønsted–Lowry theory of acids and bases, while slightly more than a third of students considered the general symbolic representation of the reaction between acids and bases to be relevant. Less than a third of students used the information when, according to the Brønsted–Lowry theory of acids and bases, a substance can act as an acid or a base. The three pieces of information mentioned are indeed relevant to formulating the required answer. At the same time, it was observed that less than 8 % of students selected some pieces of information which were not relevant to the item.

In the fourth part of the online material, the reaction between hydrogen chloride and ammonia was presented in light of the Brønsted–Lowry theory of acids and bases using the drawings of the models of molecules and ions (the submicroscopic level), and a chemical equation (the symbolic level). In the item which referred to this part, students were expected to identify which species is a proton donor and which species is a proton acceptor. Approximately 90 % of students provided a correct answer to this item, and the frequency of the answers as to which piece of information they used to answer this item is presented in Table VI.

TABLE VI. The frequencies of the pieces of information from the fourth part of the online material on the Brønsted–Lowry theory of acids and bases used for formulating the answers

Information	*N*	%
The drawings of the models of molecules and ions.	13	10.6
The equation showing the chemical reaction.	14	11.5
The drawings of the models of molecules and ions, and the equation showing the chemical reaction.	95	77.9

The majority of students based their answer regarding the fourth part of the online material on the combination of the submicroscopic and symbolic representation. Approximately 11 % of students used one or the other form of representation for formulating their answer.

In the fifth part of the online material the concepts of a conjugate acid and a conjugate base, *i.e.*, conjugate pairs, were explained using a text and symbolic representations. In the item which followed, students were expected to identify conjugate acid-base pairs in the previously considered chemical reaction. Approximately 70 % of students provided a correct answer, primarily based on the textual description of a conjugate acid and a conjugate base (Table VII). Less than half of the students used the symbolic representation for formulating their answers.

In the sixth part of the online material, the change which is caused by introducing hydrogen chloride into water was considered in the light of the Brønsted–Lowry theory of acids and bases. In the open-ended item which followed this part the students were expected to explain the acidic properties of HCl based on the Arrhenius theory and the Brønsted–Lowry theory of acids and bases. Approximately 30 % of the students provided a correct explanation according to both theories. In addition to this, a correct explanation, but only according to the Arrhenius theory, was provided by 32 % of students, while 54 % of students provided a correct explanation only according to the Brønsted–Lowry theory of acids and bases. Table VIII shows the frequency of their answers as to which part of the online material they considered to be relevant to formulating their answers (they could choose more than one part).

TABLE VII. The frequencies of the pieces of information from the fifth part of the online material on the Brønsted–Lowry theory of acids and bases used for formulating answers

Information	*N*	%
A reaction in which a positive hydrogen ion, i.e. a proton, is exchanged is called a protolytic reaction or protolysis.	15	12.3
When an acid releases a proton, it becomes a species (an ion or a molecule) which is referred to as a conjugate base.	70	57.4
A base which accepts a proton becomes a conjugate acid.	76	62.3
Protolytic reactions in which protons are accepted and donated can be shown using the following general representation: acid 1 + base 2 ⇌ base 1 + acid 2 $HA + B \rightleftharpoons A^- + BH^+$	49	40.2
The pairs acid 1 and base 1, and acid 2 and base 2 are called conjugate pairs, *i.e.*, such pairs consist of two mutually related substances.	30	24.6
This means that, according to the Brønsted–Lowry theory of acids and bases, each acid has its conjugate base and each base has it conjugate acid.	5	4.1
BH^+ is the conjugate acid of the base B, while A^- is the conjugate base of the acid HA.	39	32.0
The stronger an acid is, the weaker its conjugate base is, and the stronger a base is, the weaker its conjugate acid is.	24	19.7
These relationships influence the equilibrium composition of the system in which the protolytic reaction takes place.	17	13.9

TABLE VIII. The frequencies of the parts of the online material on the Brønsted-Lowry theory of acids and bases used for formulating the answers to items 6 and 7

The part of the online material	Item 6		Item 7	
	N	%	*N*	%
1	69	56.6	72	59.0
2	17	13.9	12	9.8
3	23	18.8	17	13.9
4	17	13.9	14	11.5
5	20	16.4	22	18.0
6	77	63.1	0	0
7	–	–	88	72.1

The most frequent answers of the students referred to the first part, which is about the Arrhenius theory, and to the sixth part. These two parts were indeed relevant to giving the answers.

In the seventh part of the online material, it was explained, in the light of the Brønsted–Lowry theory of acids and bases, what happens when ammonia is introduced into water. In addition to this, the concept of an amphoteric substance was explained and illustrated with examples. In the item which followed, students were expected to explain the basic properties of NH_3 according to the Arrhenius theory and the Brønsted–Lowry theory of acids and bases. Approximately 9 % of students provided an accurate explanation based on both theories, 10.7 % provided a correct answer based on the Arrhenius theory, and 37.7 % based on the Brønsted–Lowry theory of acids and bases. The most frequent answers of the students as to which parts of the material helped them formulate their answers and they could choose more than one answer (Table VIII), correspond to the parts of the online material which were relevant to formulating the answers.

The frequencies of correct and incorrect answers to the requirements of the post-test are shown in Table IX.

TABLE IX. The frequencies of correct and incorrect answers to the requirements of the post-test

Item	Correct answers		Incorrect answers	
	N	%	*N*	%
1. Definition of acids	113	92.6	8	6.6
2. Definition of bases	110	90.2	8	6.6
3. The explanation of the difference between the two theories	71	58.2	23	18.8
4. Identification of ampholyte (correct answer: HCO_3^-)	95	77.9	27	22.1
5. Identification of conjugate pairs (correct answers: HCO_3^-/CO_3^{2-}; HPO_4^{2-}/PO_4^{3-}; HS^-/S^{2-})	54	44.3	61[a]	50.0

[a]Students who provided an incorrect answer, who opted for both correct and incorrect answers (13.9 %), or who did not mark all correct answers (23.8 %)

By using the online material, a high percentage of students learnt what acids and bases are according to the Brønsted–Lowry theory of acids and bases (but some students were still more successful at defining acids than bases). After working with the online material more than half of the students could explain the limitations of the Arrhenius theory. More than three quarters of students could identify the species which is an ampholyte based on the symbolic representation, while less than half of them could identify conjugate acid–base pairs. The percentage of correct answers to the last item (Table IX) refers to the students who correctly chose all conjugate pairs, while the percentage of incorrect answers includes the students who chose both correct and incorrect answers or whose choice was incomplete.

CONCLUSION

The results of the conducted research study show positive effects of the application of the online material for studying the Brønsted–Lowry theory of acids and bases in slightly more than 70 % of the first-grade grammar school students. This is particularly significant in the light of the circumstances in which the instructional strategies were suddenly changed due to the COVID-19 pandemic and the fact that problems with understanding acids and bases, which are basic chemical concepts, were observed even in regular teaching circumstances.[21]

Based on the post-test results the first research question can be answered by stating that, working under changed circumstances, the majority of students learnt the definition of acids and bases according to the Brønsted–Lowry theory of acids and bases (over 90 %) by using the online material and that over half of them understood the limitations of the Arrhenius theory in explaining the acid–base properties of substances in comparison to the Brønsted–Lowry theory of acids and bases. While doing this, students learnt about the new theory autonomously, without their teacher's help.

Students' answers to the items which followed each part of the online material provide a response to the second research question about student interaction with the teaching contents. Based on the total number of the answers given (correct and incorrect), the majority of students were engaged (the average percentage of answers per item used to check the acquired knowledge was 91 %). This result is important since the application the students used to study and do assignments had been adjusted in such a way that they were obliged to answer only the items of the post-test, and they did not have to answer the items which followed each part of the online material. Such adjustment was made in order to examine the student interaction with the content of the online material. The examination into what pieces of information students had used to formulate their answers showed that a certain number of students had had difficulty with choosing the relevant pieces of information. These students needed some additional support in order to improve the comprehension of the text they had read. In the applied method of work the teacher can have a full insight into which students need additional support to what extent and with which contents. The problem which arose with the video recording in the online material (approximately 7 % of the students explained what indicated a chemical reaction between hydrogen chloride and ammonia) also occurs in the traditional classroom during demonstration experiments. Therefore, students need support with learning how to gather data about the properties and changes of substances by observing and with relating the macroscopic, submicroscopic and symbolic level.

The conducted research study showed that students could learn chemistry using online material, even for the teaching contents for which the regular teaching practice and research studies had shown to be difficult for students to understand. When preparing the online learning material, it turned out that dividing a lesson into smaller segments and checking the acquired knowledge after each segment was beneficial. The research study examined the student interaction with the content and for that purpose questions regarding the pieces of information based on which the students had formulated their answers were asked, but at the same time this step caused them to re-examine their answers by reading certain parts again. In regular practice, it would be useful to offer students some feedback information, to encourage them to re-examine the accuracy of the previously given answer and to refer them back to the parts which they had not well mastered. In the applied method of work students progressed through the teaching material at their own pace, but they all worked using the same contents. Online material which would enable students to use different contents, depending on how successfully they form their knowledge, can be designed.

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И З В О Д

ЕФЕКТИ ОНЛАЈН УЧЕЊА О ПРОТОЛИТИЧКОЈ ТЕОРИЈИ КИСЕЛИНА И БАЗА У ПРВОМ РАЗРЕДУ ГИМНАЗИЈЕ ТОКОМ ПАНДЕМИЈЕ COVID-19

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Циљ рада био је да се истраже ефекти примене онлајн материјала о протолитичкој теорији на активну конструкцију знања код ученика првог разреда гимназије током пандемије COVID-19. Припремљени онлајн материјал требало је да омогући ученицима: а) учење градива у мањим деловима; б) проверу стеченог знања након сваког дела градива; в) напредовање кроз лекцију сопственим темпом; г) визуализацију помоћу видео снимка и илустрација у циљу повезивања макроскопског, субмикроскопског и симболичког представљања садржаја о киселинама и базама; д) преиспитивање тачности датих одговора. Узорак у истраживању чинило је 122 ученика првог разреда гимназије који први пут уче о протолитичкој теорији киселина и база. Инструменти у истраживању су два теста (пре-тест и пост-тест), чију су валидност проверила два универзитетска и два гимназијска професора хемије. Примењени приступ омогућава већини ученика активну конструкцију знања, а наставницима увид у ток и исходе тог процеса.

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