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Professional paper

IMPROVING UNDERSTANDING OF PROTOLYTES THROUGH SIMULATION AND PRACTICAL TEACHING

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Abstract

This research examines the impact of different teaching methods on the acquisition of the concept of protoliths by high school students. A total of 60 second-year students at the “Kiril Pejçinović” Gymnasium - Tetovo participated in the study. The respondents were divided into three groups: a control group, where traditional teaching was applied, and two experimental groups – one with real experiments and the other with computer simulations and animations. After conducting pre- and post-intervention tests, the results showed a significant improvement in both experimental groups, where the differences were statistically significant. The group that conducted real experiments achieved the greatest improvement. In particular, an increase was observed in the percentage of correct answers to questions that required analysis and reasoning, proving that active teaching approaches help develop higher-order thinking and a deeper understanding of abstract chemical concepts.

Keywords: Protoliths, acids and bases, interactive teaching, real experiments, simulations, conceptual understanding.

1. Introduction

The concept of acids and bases is one of the most important concepts in teaching chemistry. Students encounter the terms 'acids' and 'bases' already in primary education (Aleksovska & Antonovska, 2010) at the most elementary level, as well as in the first year of secondary education (Shoptrajanov, 2006), focusing on their composition, methods of preparation, and properties. Here they are also related to their appearance and meaning in everyday life. The theories of acids and bases (Arrhenius and Brønsted-Laurieva) are studied in the thematic unit *Protolytic processes.* in the second year of secondary education. In fact, here for the first time, students encounter some of the types of chemical processes that are explained at the molecular level.

While the study of the methods of obtaining, the properties of acids and bases, and their application are relatively easy concepts for students to understand, the theories of acids and bases are quite abstract concepts, and for this reason, many students have difficulty understanding and learning them at a higher level. Usually, the explanation of the concept of acids and bases begins as it began in science itself, i.e., with the Arrhenius theory of the dissolution of electrolytes, for which he was awarded the Nobel Prize (Svante Arrhenius, 1903). He, within the framework of his theory, proposed to consider as acids substances which, during their dissolution in aqueous solutions, increase the concentration of hydrogen ions and bases, give, i.e., increase the concentration of hydroxide ions. In 1923, Brønstedt and Laurie proposed another theory. According to them, acids and bases are protolytes, that is, substances that are able to exchange protons. A substance that is a proton donor in a protolytic reaction is considered an acid, and a substance that is a proton acceptor in that reaction is considered a base. The most comprehensive theory - the Lewis theory - is not intended to be studied in secondary education, although it is presented in the most basic outlines in the introductory

chapter of the textbook for the third year of secondary education (Aleksovska & Stojanoski, 2006).
There is a lot of research on the concept of acids and bases, as one of the most important concepts in chemistry and chemistry education. Some of the research criticizes the concept that follows the historical development in the study of different theories. The proposal of the so-called hybrid model (Justi and Gilbert, 1999). On the other hand, Hawkes (1992) noted that the traditional study of the Arrhenius theory, before that of Brønstedt and Lauri, leads to confusion among students and to the creation of a large number of misunderstandings, including that there is an NH_4OH compound. The author suggests that the theory of Brønstedt and Lauri should be studied first, while the theory of Arrhenius should be mentioned only from a historical perspective without going into it. In addition, this author also proposes a new definition of acids and bases. Thus, he thinks that it is not good to define acids as *proton donors* , considering that to break the covalent bond between hydrogen and, e.g. chlorine in HCl, considerable energy is required, which means that acids do not give up protons so readily. He proposes the following definitions: "An acid is a substance from which a proton can be removed, and a base is a substance that can (has the ability to) remove a proton from an acid."
Studies by some authors, on the other hand, (Demerouti et al. 2004), showed that high school students are more familiar with Arrhenius theory, it is easier for them, so they avoid using Brønstedt and Lauri's theory to understand the concepts of acids and bases.
Sheppard's research (2006) students have difficulty in acquiring the concept of acids and bases and are unable to theoretically define the basic terms related to this topic precisely and to relate this concept to real situations. The author believes that the reasons for this are poor prior knowledge of the basics of chemistry, but also excessive solving of numerical problems that can turn into routine calculations, incorrect and confusing terminology, and the dominant role of the textbook. Confusions about terminology were also investigated by Schmidt (1995), who tested 4291 German students from grades 11-13 regarding their understanding of the Brønsted-Laury theory of acids and bases. It was found that students confuse the terms unconjugated and conjugated acid-base pairs, and that very often students think that the positively and negatively charged ions obtained as a conjugated acid-base pair neutralize each other, which also leads them to the term neutralization, which they have already encountered. This was reconfirmed by the same author in further research on the various misunderstandings that occur in relation to the neutralization process (Schmidt, 1997).
Otherwise, the way in which students understand this concept and what gaps and misunderstandings arise in doing so, has been the subject of research for a long time (Hand and Treagust, 1988; Hand, 1989). The understanding of the concept of acids and bases has also been investigated in terms of how students understand the particles that make up matter (Nakhleh, 1994). Using the concept mapping methodology, Ross and Munby (1991) observed among students a large number of gaps in their understanding of concepts that are related to each other, and similar conclusions have been reached by other authors. (Ayas & Özmen, 1998) .
Some of the research, such as that of Drechsler and Schmidt (2005), refers to the influence of textbooks and the way in which teachers themselves understand the two different symbolic representations, i.e., approaches to describing acid-base reactions: with equations in molecular form or as equations of protolytic reactions, according to the Brønsted-Laury theory. It was found that some teachers did not consider what they would apply and whether this would create confusion for students, but relied on the text given in the relevant text. On the other hand, other authors (Demircioglu, 2005) referred to the influence of curricula on the understanding of the concept of acids and bases.
Considering all these difficulties in studying this important concept, various studies have been presented in the literature to improve this situation, and a large number of them refer to the impact of visualization on the understanding of this concept and the development of higher-

level knowledge. Thus, Ozmend et al. (2009) analyzed the effects of concept mapping combined with laboratory experience to better understand the concept of acids and bases. The research was conducted among high school students from Turkey, and it was concluded that such combinations of different methods that activate students lead to a more successful mastery of this subject. Levine and Donitsa-Schmidt (1996) compared a traditional teaching method with a teaching method where student activities were implemented with the help of computers. The students were divided into control and experimental groups, and their results showed that the experimental group was more successful than the control group. Also, the application of worksheets with instructions for certain activities, but also the request for specific responses from students, showed that this activation of students leads to better results in understanding concepts and higher-order thinking (Yiğit & Akdeniz, 2000). Morgil et al. (2005) compared the results between a randomly selected experimental group, which used computer simulations in the study of acids and bases, and a control group that learned in a traditional way. Also, for both groups, he analyzed the students' skills for three-dimensional visualization, their learning methods, and their attitudes towards the use of computers in teaching. It was found that the skills for three-dimensional visualization and learning methods did not significantly affect the improvement of students' results. However, it turned out that the students of the experimental group, taught with computer simulations, showed much better results compared to the control group. Similar results are also shown by more recent research, such as that of William (2014) , who showed that the application of new teaching methods with simulations and real experiments is of great importance for improving student achievement and for their more positive attitude towards the study of chemistry.
Considering these literary data, as well as our overall goal, in the first part of our practical (quasi-experimental) research, we focused on testing the impact of active teaching with the application of real and virtual experiments (simulations) and animations on students' achievements and the development of higher-level knowledge during the study of the subject of *Protoliths* , compared to traditional teaching.

2. Research methodology

The research involved students from three second-year classes (mostly 16 years old) from a high school in Tetovo. The total number of students included in the research was 60. The selection of classes was such that they had approximately the same average success in the subject of chemistry. One of the classes in each of the high schools was selected as the control group (hereinafter referred to as CG), and the other two as experimental groups, in one of which teaching was implemented using computer simulations and animations (SG) and in the other lesson, real experiments were implemented (RG). In all three groups, teaching was carried out by the same teacher, in order to avoid the influence of different teaching styles on the knowledge acquired.

2.1 Organization of classes and research: Initially, within two teaching hours, the students were given the theoretical foundations related to this topic using a frontal way of working in the classroom. Then, a test (pre-test) was conducted in all three groups. The results of the pre-test were analyzed, but were not discussed with the students, i.e., the students were not informed about the test results. Based on the perceived weaknesses, but also depending on the possibilities, activities were designed with the experimental groups and carried out within one hour. In the control group, on the other hand, a lesson was held to repeat and determine the knowledge acquired, during which the teacher paid attention to the perceived weaknesses and omissions of the students.

The activities involved the application of the acid-base solution program from the PhET package (PhET, Capacitor Lab., 2010) and the Crocodile chemistry application (crocodile chemistry, 2006). The PhET and Crocodile chemistry applications were installed on the school computers. These applications offer the possibility of applying simulation experiments, but in addition, during their explanation, one can follow animations that give an idea of the process at the molecular level. After completing the activities, the students presented what they observed while performing the activities and what conclusions they could draw from them, and then a critical discussion was opened. Then, after a week, the students from the three groups solved a test (post-test), which was in fact the same test that was given to them before implementing the activities.

2.2 About the test: The test consisted of 10 questions. Three of them were open-ended with a request for an explanation of the question; one was open-ended where the student was asked to draw a picture; four of the questions were closed-ended in the form of multiple-choice questions with one correct answer; one was an oral question, and one was a table-filling question. When choosing the questions, we were guided by the manual *Questions and Tasks in Chemistry for the Second Year of Gymnasium* (Shoptrajanov, 2003), but these are not the same questions, but questions that will be in the context of the material given in the text.
Since the aim of the research was to provide a quantitative representation of students' achievements by applying different teaching approaches, we decided that each question would have a maximum of 10 points. One of the questions (the first) could carry either 5 or 10 points, and one of the questions (the sixth), where 4 particles had to be classified as acid, base, or amphiprotol, could be given either 0 points or 2.5 - 10 points. Open questions required a yes or no answer, but then also required an explanation of the answer. Such questions were considered correct only if they were answered correctly and correct justifications were given, which means that they could be scored 0 or 10 points. Finally, the quantitative processing of the results was done by statistical processing of the points obtained from the tests, with the StatgraphicsPlus software package (Statgraphics plus, 1994).

3. Results and discussion

The results of the testing performed are given in Table 1. As can be seen from Table 1, in all three groups, the knowledge control results are higher in the post-test than in the pre-test. An indication of how statistically significant the difference between the post-test results and the pre-test results is can be seen from the *t -test value* at a significance level of $\alpha = 5\%$. With this test, the mean values are compared to check whether the null hypothesis is valid, which assumes that there is no statistically significant difference between the mean values of the two samples. Otherwise, in all cases, the program also calculates *the F* -test which shows whether there is any statistically significant difference between the variances (i.e. the squares of the standard deviations) of the two samples. In all cases, the value obtained for *the F* -test was smaller than the critical one, which means that there is no statistically significant difference between the standard deviations of the two samples. Therefore, the program calculates *a T* -test according to the formula for samples with equal variances. Values for the *t test* ($t < t_{cryt.}$) show that the difference between the average success of the post-test and pre-test in the control group is not statistically significant, while in the two experimental groups ($t > t_{cryt.}$) is statistically significant, indicating that this is most likely due to the applied activities. The largest difference in average success was achieved in the group that performed real experiments (19.15%), which actually represents 39.5% of the success shown in the pretest, while in the group that used computer simulations, it was 36.69%.

Table 1. Comparison of pretest and posttest results for the control group (CG) and the two experimental groups (RG and SG) from Tetovo. *N* is the number of students; $\bar{x}$ is the average score; s is the standard deviation; $\Delta\bar{x}$ is the difference in post-test and pre-test success; t is the test statistic result, and *t is* $_{\text{the cryt}}$. is the critical value; and the confidence interval pe.

Statistically PARAMETER	**KG**		**RG**		**SG**	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
N	18	18	23	23	21	21
$\bar{x}$/%	39.25	49.08	39.50	58.65	36.69	50.55
s	18.52	21.94	17.01	17.73	15.19	18.82
$\Delta\bar{x}$/%	9.83		19.15		13.86	
the	1.32		3.05		2.35	
to $_{\text{cry.}}$	1.59		2.04		2.05	
p	0.1538		0.0042		0.0203	

For all three groups, a statistically significant difference was found in the average success achieved between the post-test and the pre-test. And in this case, the largest difference is between the average success of the pre-test and the post-test in the group that performed real experiments (the difference is 19.15%, which means an improvement of approximately 45%). What is of particular importance in this research is the analysis of the questions answered in the pre-test, to see what is less acquired, what is not understood, where the students have problems, and what they have misunderstandings about. Then, based on the results of the questions answered in the post-test, see if the applied teaching methods and activities contributed to the elimination of problems and to a better and deeper understanding of the concepts. The average success results for each of the questions in all groups are given in Table 2.

Table 2. Average success, expressed in percentage, for each of the pre-test and post-test questions and their difference for each of the groups in Tetovo.

A question	KG			RG			SG		
	Post-test $\bar{y}$/%	Para-test $\bar{y}$/%	$\Delta\bar{y}$/%	Post-test $\bar{y}$ %	Para-test $\bar{y}$/%	$\Delta\bar{y}$/%	Post-test $\bar{y}$/%	Para-test $\bar{y}$/%	$\Delta\bar{y}$/%
1.	85.10	73.22	11.88	88.13	72.13	16.00	87.09	74.81	12.28
2.	37.89	34.33	3.56	46.82	31.43	15,39	25,81	24,81	1.00
3.	54,55	13,11	41,44	64,21	15.04	49,17	32,33	11,52	20,81
4.	71,22	63.11	8,11	66,21	60,86	5,35	79,95	63,91	16,04
5.	43,44	38,88	4,56	51.17	41,47	9,70	60,80	31,23	29,57
6.	54,84	50,68	4.16	61.50	47,81	13,69	53,55	45,83	7,72
7.	21,32	10,54	10,78	32,68	16.59	16,09	8,73	8,43	0.3
8.	21,52	17,56	3.96	41,68	29.33	12,35	17.15	16,95	0.2
9.	81,43	76,57	4.86	80,40	75,16	5.24	78,85	82,51	-3,66
10.	37,57	36,48	1.09	63,11	38.33	24,78	59,74	21.57	38,17

The analysis of the responses to the questions revealed some interesting and unexpected results. The first question was from the first level of Bloom's Taxonomy and required linking sentence fragments to make definitions of Arrhenius acid and base, and Brønstedt-Lauric acid and base. The question was worth 10 points or 5 points if only one of the definitions of acids and bases was guessed (i.e., two correct links). For this question, we expected a high percentage of correct responses in both the pre-test and post-test, even 100% correct responses. In fact, this question had the highest percentage of correct responses for all groups in the post-test. But even though they responded with a fairly high percentage in the pre-test, it turned out that some students did not understand the meaning of the words "donor" and "acceptor", so they wrote that acids are proton acceptors and bases are proton donors. In the post-test, the results in all groups improved, due to the fact that these concepts are repeated many times during the repetition and definition of knowledge with traditional teaching, but also through activities in the two experimental groups and in the discussion that followed.

The second question is open-ended and requires the student to say whether, according to Arrhenius theory, pure gaseous ammonia is a base, but also to give an explanation for their opinion. As we said above, we considered this question as a correct answer only if the reasoning was also correct. The correct answer was considered the one in which the student states that pure gaseous ammonia is not an Arrhenius base, because according to Arrhenius theory, we can only talk about acids and bases if we talk about their aqueous solutions, and the base should increase the concentration of OH^{-} ions in aqueous solution. The percentage of correct answers to this question in the pre-test was 34.33% for the control group in Tetovo, which represents a small percentage of answers. This question can be considered to be from the fourth (or even fifth) level of Bloom's taxonomy. In fact, in this case, as in other cases with open questions, when the student needs to explain or explain something, i.e., argue their opinion, the percentage of correct answers is small. Students do not even try to answer the question. Thus, in most cases, the students answered that gaseous ammonia is not a base according to the Arrhenius theory, but without explaining why they think so. In some answers, they even wrote that the base can only be gaseous NH_4OH. This shows that some students have a completely wrong idea about the existence of gaseous ammonium hydroxide, and perhaps even in a solid aggregate state. The post-test showed that all groups showed better results.

A big surprise for us was the results of the answers to the third question. This is a multiple-choice question (four) of which only one is correct. The purpose of this question is to check how much the students have mastered the symbolic representation of protolytic reactions, therefore, it is required to solve the equation that most accurately represents the process of protolysis when gaseous HCl is introduced into water. The percentage of correct answers in the pre-test was 13.11%. Most students chose the distractor $HCl(g)=H^{+}(aq)+Cl^{-}(aq)$, probably because only there HCl is in the gaseous aggregate state shown. The post-test showed significant improvement in all groups. There is also progress in the experimental groups, but it cannot be attributed to the activities themselves that were carried out, but to the questions and discussions that followed after the activities were completed. The errors in the post-test are mainly due to the choice of the distractor a) $HCl(aq)=H^{+}(aq)+Cl^{-}(aq)$, instead of the correct one b) $HCl(aq)+H_2O(l)=H_3O^{+}(aq)+Cl^{-}(aq)$. This means that some students have not yet understood and have not learned that acid/base pairs always participate in a protolytic process, although this is clearly stated in the textbook and during the lectures, and through the activities themselves.

The fourth question is, like the previous one, of the closed type, i.e., a question with a choice of the correct answer from several offered, which we consider to be from the fourth category of Bloom's taxonomy (analysis), because the student must analyze the offered answers and make the distinction to arrive at the correct answer. It turned out that this is one of the questions with the best answers, and even in the pre-test. This is most likely due to the possibility of arriving at the correct answer by analyzing the products in the reaction equation. Namely, everywhere one of the products is H_3O^{+}, except in the correct answer, where it is OH^{-}. However, some of the students did not even try to answer this question, and some chose the distractor b) perhaps not knowing that HCN is an acid and not analyzing the reaction products in the provided equations. In the post-test, the three SGs made the greatest progress, which was due to the animations of protolithic processes involving water, which they followed during the activities.

In the fifth question, students are asked to choose which of the pairs provided corresponds to an acid/conjugate base pair. What is particularly important to note is the choice of distractors in the wrong answers. Even in 90% of the questions with wrong answers, distractor b) was chosen. This shows that some of the students did not distinguish between acid/base and conjugate acid/base pairs. Furthermore, this shows that even closed questions, if well-designed distractors are provided, can reveal a lot about students' thinking and misunderstandings. Even in the other control groups, the improvement compared to the pretest is not very large, although during the repetition and determination of knowledge, great attention was paid to this problem. The progress in the experimental groups was due to the animations they watched (SG) and the questions asked on the worksheets and the discussion after them (in both SG and RG).

In question six, students can score from 2.5 to 10 points for correctly classifying each of the four species as a Brønsted acid, a base, or an amphiprotolite. This question can be classified as the third category of Bloom's taxonomy because it partially requires the application of acquired knowledge to new situations. Namely, the behavior in aqueous solutions of some of the species given in the question is discussed in the text or mentioned in the introductory class, but some are not mentioned in the textbook or in the teacher's presentation, such as HCO_3^-. The pre-test showed that only three students scored a total of 10 points. The largest number of students scored 5 points by correctly classifying HBr and H_2O; some correctly classified the sulfate anion, but almost no one correctly classified the HCO^{3-} ion. It is either not classified or is considered an acid because it contains a hydrogen atom. Due to this scoring method, in all the analyzed classes of the pre-test, the question was answered correctly by about 50%. In the post-test, better success was achieved in all groups, but none of them can be said to have been the most successful. We expected that the problem of classifying HCO^{3-} would be solved better in the control groups because the teacher explained the amphoteric properties of some hydrogen anions to the students through other examples. Although there was an improvement in the average response to this question, the overall result is not very high.

The seventh question proved to be the most difficult for the students and with the worst results. The question is of the open type and requires the student to decide whether the reaction represented by the equation $NH_3(g)+HCl(g)=NH_4Cl(s)$ is protolytic, but also to explain their opinion. We consider this question to be from the assessment category according to Bloom's taxonomy. In reasoning, students are expected to know that ammonium chloride is an ionic compound and that ammonium ions are formed by the transfer of a proton from HCl to the electron pair of the nitrogen atom in the ammonia molecule. As in the case of other questions where explanation is required, in this case, even when students answered positively that it was a protolytic reaction, they were unable to explain it, so in most cases, they did not provide an explanation at all. A large number of students wrote that it was not a protolytic reaction because they thought that a solid could not be obtained from two gases! In the post-test, a significant improvement is observed, mainly in RG, because one of the activities is precisely the direct synthesis of NH_4Cl from gaseous ammonia and gaseous HCl. Questions and discussion about the experiment contributed greatly to the improvement of the result.

The eighth question is also open-ended and from the assessment category of Bloom's Taxonomy. In the question, it is initially stated that a protolith behaves as a good proton donor and a poor proton acceptor. This sentence is deliberately phrased this way, so that they first think about what it means for a substance to be a proton donor, and what it means to be a proton acceptor, and that if it is a better proton donor, it means that its acidic properties dominate. Then the question is asked: "Can this protolith also act as a base?" and then the justification of the answer is required. The students were expected to write in the explanation that the same substance, depending on the partner, can act as both an acid and a base. This is clearly emphasized several times in the textbook and during the teacher's presentation, so we expected a high percentage of correct answers to this question already in the pretest. It turned out that the pre-test results are very weak, 17.56 % (KG) to 29.33 (RG). However, no progress was observed in SG. Again, we cannot find an adequate explanation for this result. In fact, with this group, we have up to three questions without any change in success from pre-test to post-test. In the conversation with the students, some of them answered that in the post-test, they paid more attention to those questions that they thought were related to their activities.

A big surprise for us was the high percentage of correct answers to question 9 in the pretest as well. The question is of the closed type and asks how the conjugate base of a strong acid will behave, in the sense of how strong the conjugate base will be. In the pretest, this was the question with the best answer for all three groups. A slight improvement was achieved in the post-test, because the percentage of correct answers was also high in the pretest. However, in the case of SG, it was observed that the post-test had a lower percentage of correct answers compared to the pretest. This signaled to us that some students may have chosen the correct answer quite randomly. Of course, there is a risk of randomly guessing the correct answer to the questions by choosing one correct answer from several provided answers. However, considering the success of all groups in all such questions, we can conclude that the probability of finding the correct answer by chance is low. But the test itself consists of different types of questions, which makes the test even more valuable for drawing conclusions about the effectiveness of the methods applied in teaching. In the conversation with the students, after completing all the activities, we found that some students, simply logically, concluded that if the acid is strong, its conjugate base will be a weak protolyte, but this was emphasized several times by the teacher.

We considered question ten to be a creation-type question because students were required to draw a picture illustrating a solution of a weak acid with drawn molecular models and to draw a bar graph showing the relative concentration of the particles present in the solution. Students were expected to know that in weak protolytes, an equilibrium is established between the unprotonated acid or base and the conjugated base or acid. This question is related to the section of the learning material titled *Protolytes in the text. balances*. Here, we were not only surprised by the low percentage of correct answers in the pretest, but also by the fact that we discovered a misunderstanding among a large number of students. Namely, some of the students presented a dilute solution of a strong acid, instead of a solution of a weak acid, which means that they equated these two terms. Some students even simply drew the acid and the conjugate base of water, as shown in the picture below.

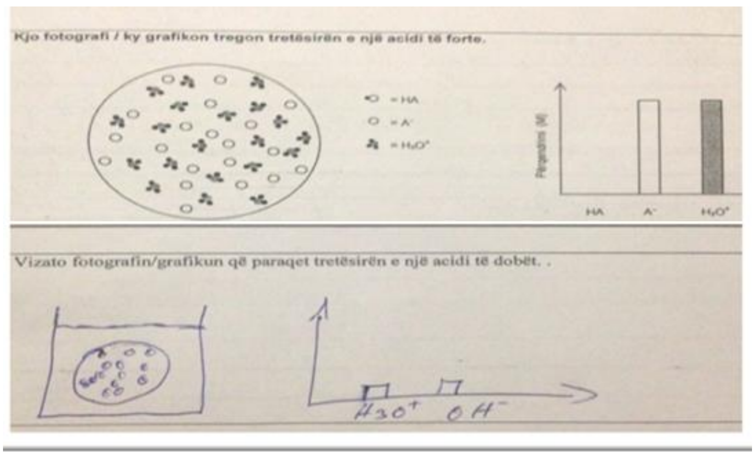

Figure 1. One of the answers to the tenth question of the test.

The percentage of correct answers to this question in the pretest for all groups is around 30% (from 21.57% to 36.48%). It was shown that in all three groups that had activities with computer simulations, success improved significantly (by 59.74%), which is due to the activity in which the student chooses to make a solution of a strong and weak acid or base, which is followed by an appropriate view of the composition of the solution and the relative concentration of particles in the solution. Better results were also achieved by the groups that performed real experiments.

4. Conclusion

From the research presented above, several conclusions can be drawn. Initially, it should be noted that the application of traditional teaching in the studied groups showed a relatively low average success rate (about 40%), which can be concluded from the results of the pre-test. This is mainly because this is an abstract topic in which many new concepts are introduced, which can only be understood if the student has solid prior knowledge of previous topics. Moreover, from the pre-test, several misunderstandings were noted (some of them have also been noted in the literature), such as equating a weak acid with a dilute acid, then the misunderstanding that protolytic processes occur only in solution, etc. All this could be concluded because the test itself was designed to cover all aspects of this topic, but also to check the knowledge and understanding of the students in the reassessment of the tax. implies understanding and recognition of a higher level, of course, taking into account the age of the students.

The research showed that in the post-test, all three groups showed better results. This was due to the additional activities in all groups, but the teaching methods that were applied in the experimental groups to better understand the topic and to remove gaps and misunderstandings gave a better result than the application of traditional teaching in the control group. The best results were obtained in the groups that conducted real experiments.

The analysis of the correct answers to the questions shows that the application of appropriate computer software packages, which visualize these processes, can significantly contribute to the understanding of processes at the molecular level. In fact, both the activities related to the application of the computer, as well as the performance of real experiments, will yield results only if they are accompanied by requirements for the student himself to draw conclusions from the activity performed and then to check his thoughts and answers with a joint discussion in the classroom, during which final, but also correct, conclusions will be drawn. Insufficient or misunderstood terms were also clarified in the control groups, but here the main word was the teacher, and only a small part of the students actively participated in the class work. We would also add to this that in the experimental groups, the students were more motivated and more interested in the work, precisely because they themselves were actors in the teaching.

Here we should also emphasize that organizing a lesson with active participation of students, but with previously prepared instructions for carrying out activities in the form of a worksheet and questions related to them, can also give bad results and lead to the creation of an even greater number of misunderstandings. This can happen if all activities are not discussed at the end and if the teacher does not check that the questions asked on the worksheet are answered correctly, because it may happen that students draw wrong conclusions. Therefore, at the end of the lesson, all activities, i.e., the conclusions from them, should be discussed with the teacher and under his control, the questions should be answered correctly. Therefore, it is important not only to formally move on to the learning unit, but, as indicated in the requirements of modern education, the teacher adapts the lesson to the needs and achievements of the students. This means that if all activities are not completed within the specified time, they should continue in the next class. Unfortunately, this approach to teaching is rarely practiced in our schools.

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