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Research Article

The Effects of Computer Simulations and Real Experiments to Understand the Concepts of Acids and Bases

Chemistry

Keywords: simulations and real experiments; acids and bases; new concepts and misconceptions.

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Abstract

The purpose of this study was to investigate the effects of computer simulations and real experiments on understanding the concepts of acids and bases. New teaching methods were focused on gaining conceptual knowledge. The investigation was performed on a sample consisted of two hundred and eleven students. The research was carried out with experimental groups and control group. In aim to measure the gained knowledge, a conceptual test of knowledge was performed, and the test results were statistically processed. The results indicated that the students in the experimental groups, showed significantly greater achievement in comparison with the students in the control group. This shows that the implementation of computer simulations and real experiments produced better results in understanding of this concepts and removing the misconceptions.

Introduction

The concept of acids and bases is one of the most important in teaching chemistry. In Macedonia, students meet the concept of acids and bases at early stages of their education, but focusing on their composition, preparation and properties and meaning in our everyday life. The theories on acids and bases, Arrhenius's and Brønsted's, are studied in the topic Protolytic processes in the second year of gymnasium secondary education. In fact, within this topic, the students for the first time meet with chemical processes explained at a molecular level. While the study of preparation, properties and application of the acids and bases are relatively easy to understand, theories on acids and bases represent quite abstract concepts and are therefore difficult to be comprehended and studied at higher levels by the students. Usually, the explanation of this concept begins as it did in science itself, i.e. Arrhenius's theory on electrolytic dissociation and then the Brønsted and Lowry acid-base theory.

There have been many studies on the acid-base concept in the science of chemistry as well as in chemistry related education subjects. Some approaches criticize the concept of studying different theories based on their historical development and suggest the so called hybrid model (Justi and Gilbert, 1999). Hawkes (1992), on the other hand, noticed that traditional studying of Arrhenius's theory, before those of Brønsted and Lowry, causes confusion in students' understanding and creates a series of wrong ideas, as is the one of existence "NH4OH" substance. The author suggests that Brønsted's theory should be studies first, whereas Arrhenius's theory should be mentioned only from the historical point of view without getting much into it. In addition, this author suggests a new definition for acids and bases. He considers that it is not correct to define acids as donors of protons, having in consideration that in order to break the covalent bond between the hydrogen and for example, chlorine in HCl, a considerable energy is needed, which means that acids do not donate their protons very easily. He suggests the following definition: "An acid is a substance from which a proton can be removed, whereas a base is a substance which has the ability to remove that proton from the acid."

On the other hand, the research carried out by some other authors (Demerout et al., 2004), have shown that high school students are more familiar with Arrhenius theory; it is easier to them and they avoid using Brønsted's theory on understanding the concepts of acids and bases. Based on some studies (Sheppard, 2006), students find it difficult to embrace the concepts of acids and bases and could not theoretically and precisely define the basic concepts related to this topic, nor link them to real situations. The author thinks that the causes for this are poor pre-knowledge about the basics of chemistry, overstuffed nature of introductory chemistry itself, the emphasis during instruction on solving numerical problems, which can become routine calculations, the imprecise and confusing terminology, and the dominant role of the textbook. The confusion that has emerged regarding the terminology was examined by Schmidt (1995) who tested 4291 German students from 11th and 13rd grades with regard to their understanding of Brønsted-Lowry theory on acids and bases. It was concluded that students mix up notions such as conjugated and non-conjugated acid-base pairs, and that they quite often think that positive and negative ions, which are obtained as a conjugated pair of acid and base, are mutually neutralized; this is caused by the notion of neutralization, which has previously been met by them. This was again confirmed by the same author in his further studies on different misconceptions, which emerged during the process of neutralization (Schmidt, 1997).

Actually, the way students understand this concept along with all the deficiencies (Hand & Treagust, 1988) and false representations (Hand, 1989) has been a subject of number of research studies. Understanding the concept of acids and bases has been studied in relation to the way students understand particles of which the matter is composed (Nakhleh, 1994). By using the methodology of conceptual map, Ross and Munby (1991) had noticed great gaps in students' understanding of the concepts which are related to one another.Some researches, such as those by Drechsler and Schmidt (2005) refer to the impact of textbooks and to the issue of how teachers themselves understand the two different models, i.e. approaches towards the description of acid-base reactions: as equations in molecular form or as equations of protolytic reactions based on the Brønsted-Lowry theory. It was confirmed that some teachers did not take into account what they were going to implement and whether it would cause confusion in students; instead, they relied on the text given in the textbook. Other authors, on the other hand, (Demircioglu et al., 2005) dealt with the influence of study programs on understanding the acid-base concept.

Because of all these difficulties in studying this important concept, various different studies in improving the current situation have been presented in literature; the majority of them refer to the impact of visualization on understanding this concept and developing knowledge at higher levels. In this respect, Levine and Donitsa-Schmidt (1996), compared traditional teaching methods to those where computer based activities were used whereupon students had been divided into a control (traditional teaching) and experimental group (computer-based teaching). Their results showed that the experimental group was more successful than the control group. In addition, the worksheet with instructions for certain activities, as well as the request for concrete answers by students, showed that this kind of students' activation and motivation leads towards better results in their understanding of concepts and ideas at higher levels (Yiğit and Akdeniz, 2000). Morgil et al. (2005) compared the results between the randomly chosen experimental group, which undertook computer simulations in studying acids and bases, and the control group taught using traditional approach. In both groups student abilities in three-dimensional visualization, their study modes and their attitude towards computer application in teaching/learning had been analyzed. It was concluded that students' abilities in three-dimensional visualization and their study modes did not influence much the improvement of student performance. However, it was also proved that students from the experimental group, taught through computer simulations, showed much better results compared to the control group. Similar results are drawn from more recent studies, such as the one by William (2014), who showed that the application of new teaching methods with simulations and real experiments is very important in terms of improving students' performance and outcomes and their more positive attitude towards learning chemistry.

Having in consideration these data acquired from different sources, as well as our general objective, the first part of our study was directed towards the examination of the influence of active teaching methods through the application of real experiments and computer simulations and animations on students' performances and development of higher level skills and knowledge, compared to traditional teaching methods, in studying the topic *Protolytic Proceses.*

Research methodology

2.1. The samples

Students from three different classes of second grade (aged mainly 16) from three gymnasium secondary schools in Tetovo, Kichevo and Debar were included in the study. Their total number was 211. The selection of classes was based on the similar success in the subject of chemistry. One of the classes was selected as a control group (CG), whereas the other two as experimental groups, of which one was taught using computer simulations and animations (SG), and the other was taught using real experiments (RG). In all three groups, the teaching was performed by the same teacher, in order to avoid the impact of different teaching styles on the acquired knowledge.

2.2. Organization of teaching and students' activities

Firstly, within the framework of two class hours, the theoretical basics of this topic were presented through the traditional "ex cathedra" approach. Then, a pre-test with the three groups was done. The results were analyzed, but were not discussed with the students and they were not informed about their achievements. Based on the test results, certain activities were planned with the experimental groups to be carried out within a class hour in aim to eliminate the detected wrong answers, weaknesses and misconceptions. In the control group, a revision class was performed, whereupon the teacher paid attention to detected weaknesses in students' knowledge.

With the students of RG, the class hour was organized in small groups. They were divided into five groups with 4-5 students randomly selected. Each group received a worksheet with instructions about the activities they were supposed do. After they finished with their activities, the teacher opens a discussion related to the experiments and the responses to the questions of the worksheet. Even though this topic is not that appropriate for experimental teaching, there were some experiments regarding the detected weaknesses in the pretest. Students had to do five simple experiments under the teacher's supervision. The first one was about differentiating between an acid and a base based on the change in color of the universal indicator strip. The aim of the next experiment was to observe the protolytic reaction of ammonia and water. The objective was students to realize that although ammonia is not Arrhenius base it is a base according to the Brønsted-Lowry theory. Then there is another experiment, namely the reaction between gaseous ammonia and gaseous HCl whose objective is students to understand that protolytic reactions can occur between gaseous substances and not only in solutions. The last two experiments dealt with the relative strength of acids and bases. These experiments were chosen in aim students to realize the difference between the weak acid or base and diluted acid and to recall to chemical equilibrium.

Students from the SG performed their activities in pairs. They also received worksheet with instructions for every activity and questions related to the conclusions from their activities. The activities were performed with the implementation of the application acid-base solutions from the PhET software package (2010) and Crocodile Chemistry (2006). The PhET application was already installed in school computers, whereas Crocodile Chemistry was additionally installed just before the class started. These applications offer the possibility of using simulated experiments as well as animations, which can help visualization of the processes at a molecular level. After the accomplishment of activities, the students presented what they had learnt and discussed. Then, a week later, the post-test was performed.

2.3. The test

The test consisted of 10 questions including open-ended and multiple choice questions. Since the aim of the study was to obtain some kind of quantitative idea about the students' achievements by implementing different approaches in teaching, we decided to asses every correct question with maximum 10 points. One of the questions (the first) was evaluated with 5 or 10 points and one of them (the sixth) where they had to classify 4 particles as acids, base or amphiprotolyte was evaluated with 0 or 2.5 – 10 points. Open-ended questions were supposed to be answered with yes or no but then they had to provide explanations to those short answers. These questions were evaluated as correct only if they were properly answered along with the explanations that mean that students could either get 0 or 10 points. The questions of the test are being explained in Results and Discussion heading.

At the end, the quantitative analysis of the results was done through a statistical processing of the points earned, by using the StatgraphicsPlus (1994) computer package.

Results and discussion

The pre-test and post-test results of the students from the three secondary schools are given in Tables 1. As can be seen, in all three groups the average score of the post-test is better than of the pre-test. The indicator for the statistical significance of the difference between the average score of the post-test and pre-test can be seen from the value of the t-test at the significance level of $\alpha = 5$ %.

The t-test show that the difference between the average score in the post-test and pre-test in the CG of Tetovo and Debar is not statistically significant ($t < t_{cryt.}$), but in Kichevo it is. However, for the experimental groups (both RG and SG), from all three cities, the difference between the average score in the post-test and pre-test ($t > t_{cryt.}$) is statistically significant which implies that this is due to the implemented activities.

The biggest difference in the average score for the groups in Tetovo was detected in RG (18.15 %), which is in fact 43.7 % better result compared to the pre-test, whereas in the SG this percentage was 33.24 %. Also, The RG from Kichevo, showed the biggest difference in the average score between the pre-test and post-test (the difference was 21.40 %, which means an improvement of about 47 %). The differences between the average score in the post-test and pre-test for the two experimental groups from Debar are almost identical, even though there is a slightly higher difference in the score of the RG (23.02 %).

In general, if one analyze the average score of all groups that performed the test (both the pre-test and post-test), we can conclude that it is not very high, which implies that the topic itself is quite difficult for the students.

What is important in this study is the analysis of answered questions in the pre-test so that all the problems that students may have faced previously could have been detected. Then, based on the results from the answered questions in the post-test, we could see whether the implemented teaching methods and activities have contributed to the elimination of problems and better understanding of notions. The results from the average score for each question in all groups have been given in Table 2.

The analysis of students' answers to the questions showed some interesting and unexpected results. The first question was from the first level of Bloom's taxonomy whereupon students were asked to match parts of sentences so that they could compose the definitions by Arrhenius and Brønsted & Lowry regarding acids and bases. The question was assessed with ten or five points, depending if they answered to both definitions or just one of them. This question was the most accurately answered question in all groups in the post-test, except the SG in Debar. Despite the high percentage of correct answers in the pre-test, we noticed that certain students could not understand notions like donor or acceptor, and had written down that acids are proton-acceptors and bases are proton-donors. In the post-test, the results in all groups were improved, due to the frequent repetition of the above-mentioned notions and their explanation through traditional teaching methods combined with the activities in the two experimental groups and the discussion afterwards.

Table 1. Comparison of the results from the pre-test and post-test for the CG and two experimental groups (RG and SG). N is the number of students; is the average score; is the difference in the success between the pre-test and post-test; t is the result of the test-statistics; tcrit. is the critical value; df is the number of degrees of freedom; p is the reliability interval.

Statistical Parameter	CG		RG		SG	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Tetovo						
N	18	18	23	23	21	21
$\bar{x}$ /%	41.25	52.08	42.50	60.65	38.69	51.55
s	20.52	24.94	20.01	20.73	17.19	19.82
$\Delta\bar{x}$ /%	10.83		18.15		12.86	
t	1.42		3.02		2.25	
$t_{cryt.}$	1.69		2.01		2.02	
p	0.1638		0.0042		0.0303	
Kichevo						
N	26	26	25	25	24	24
$\bar{x}$ /%	44.23	57.31	45.60	67.00	41.77	58.85
s	19.40	25.30	16.24	20.88	15.99	16.25
$\Delta\bar{x}$ /%	13.08		21.40		17.08	
t	2.09		4.04		3.67	
$t_{cryt.}$	2.01		2.01		2.01	
p	0.0416		0.0002		0.0006	
Debar						
N	24	24	24	24	26	26
$\bar{x}$ /%	46.25	54.37	41.25	64.27	38.36	59.33
s	17.71	22.13	15.91	21.13	19.30	18.15
$\Delta\bar{x}$ /%	8.12		23.02		20.97	
t	1.40		4.26		4.03	
$t_{cryt.}$	2.01		2.01		2.01	
p	0.1669		0.0001		0.0002	

Table 2. Average score, in %, for every question in the pre-test and post-test and their difference.

Q.	KG			RG			SG		
	Post-test $\bar{y}$ /%	Pre-test $\bar{y}$ /%	$\Delta\bar{y}$ /%	Post-test $\bar{y}$ /%	Pre-test $\bar{y}$ /%	$\Delta\bar{y}$ /%	Post-test $\bar{y}$ /%	Pre-test $\bar{y}$ /%	$\Delta\bar{y}$ /%
Tetovo									
1.	86.10	72.22	13.88	89.13	71.13	18.00	88.09	73.81	14.28
2.	38.89	33.33	5.56	47.82	30.43	17.39	23.81	23.81	0
3.	55.55	11.11	44.44	65.21	13.04	52.17	33.33	9.52	23.81
4.	72.22	61.11	11.11	65.21	60.86	4.35	80.95	61.91	19.04
5.	44.44	38.88	5.56	52.17	43.47	8.70	61.94	33.33	28.61
6.	56.94	51.38	5.56	60.70	48.91	11.79	55.95	46.43	9.52
7.	22.22	11.11	11.11	34.78	17.39	17.39	9.53	9.53	0
8.	22.22	16.66	5.56	43.78	30.43	13.35	19.05	19.05	0
9.	83.33	77.77	5.56	82.60	78.26	4.35	80.95	85.71	-4.76
10.	38.89	38.88	0.01	65.21	30.43	34.78	61.94	23.81	38.13
Kichevo									
1.	86.53	76.92	9.61	94.00	84.00	10.00	89.58	77.08	12.50
2.	50.00	26.92	23.08	56.00	20.00	36.00	41.66	20.83	20.83
3.	38.46	11.53	26.93	56.00	16.00	40.00	45.83	25.00	20.83
4.	73.07	69.23	3.84	92.00	84.00	8.00	79.16	58.33	20.83
5.	57.69	38.46	19.23	60.00	44.00	16.00	45.83	33.33	12.50
6.	55.76	50.00	5.76	64.00	52.00	12.00	65.62	53.12	12.50
7.	34.61	23.08	11.53	56.00	20.00	36.00	29.16	16.67	12.49
8.	46.15	30.77	15.38	56.00	28.00	28.00	45.83	25.00	20.83
9.	84.61	80.77	3.84	84.00	73.00	11.00	83.33	79.16	4.17
10.	46.15	34.61	11.54	84.00	36.00	48.00	62.50	29.16	33.34
Debar									
1.	85.41	79.16	6.25	95.83	85.42	10.41	84.61	71.15	13.46
2.	41.67	25.00	16.67	54.17	20.83	33.34	30.76	23.07	7.69
3.	25.00	12.50	12.50	54.17	16.67	37.50	53.84	15.38	38.46
4.	83.33	79.17	4.16	75.00	62.50	12.50	84.16	53.84	30.32
5.	54.17	54.17	0	70.83	45.83	25.00	50.00	15.38	34.62
6.	62.50	50.00	12.50	63.54	56.25	7.29	54.81	47.11	7.70
7.	25.00	25.00	0	41.67	12.50	29.17	19.23	11.53	7.70
8.	41.67	29.17	12.50	54.16	25.00	29.16	53.84	23.08	30.76
9.	83.33	75.00	8.33	79.17	58.33	20.84	92.31	92.31	0
10.	41.67	33.33	8.34	54.17	29.17	25.00	69.23	30.76	38.47

The second question was open-ended and it required from students to say whether, based on Arrhenius's theory, the pure gassous ammonia is a base, and to explain their answer. As we said above, this question was considered correct if the explanation was correct too. The correct answer was that in which the student would have answered negatively, because in Arrhenius's theory, we can talk about acids and bases only in aqueous solutions and the base should increase the concentration of OH – ions in them.

The percentage of correct answers to this question in the pre-test was about 20 % in the RG in Kichevo to 33.33 % in the CG in Tetovo, which is a low percentage, even though it belongs to the fourth (or even fifth) level of Bloom's taxonomy. In fact, in this case, as in all other cases of open-ended questions, when students have to explain things, the % of correct answers is low. Students do not even bother to answer the questions. Therefore, in most cases students answered that the gaseous ammonia is not a base according to Arrhenius's Theory, but they did not explain their answers. In some other cases, they even said that only the gaseous NH4OH can be a base. This shows that some students have a completely wrong picture or misconception of the existence of the gaseous ammonium hydroxide, and even a solid state. In the post-test, all groups achieved better results, except the SG in Tetovo. We are merely unable to explain the reasons for this phenomenon. It is noticeable that in the three control groups there was some improvement due to the additional explanations by and the discussion with the teacher during revision classes; however, the greatest progress was measured in the RGs, which we could explain through the questions which they had to answer in the activity 2 of the worksheet.

A great surprise to us was the answers to the third question, which was a multiple-choice question with only one correct answer out of four. The aim of this question was to check whether and at what degree the students had absorbed the symbolic presentation of protolytic reactions and were therefore asked to choose the equation which best represents the process of protolysis of gaseous HCl in water. The percentage of correct answers in the pre-test was from 9.52 % (SG, Tetovo) to 25 % (SG Kichevo). The majority of students chose the distracter HCl(g) = H+(aq) + Cl–(aq), most probably because it is the only equation in which HCl is labeled in a gaseous aggregate state. In the post-test, we could see significant progress in all groups. In the control groups in Kichevo and Tetovo, it was exactly this question (out of the total of ten questions) in which students achieved the greatest progress. Progress occurred in the experimental groups as well, but they cannot be attributed solely to the realized activities but rather to the questions, answers and the discussion that followed afterwards. Most of the wrong answers in the post-test are mainly due to the selection of the distracter a) HCl(aq) = H+(aq) + Cl–(aq), instead of the correct option b) HCl(aq) + H2O(l) = H3O+(aq) + Cl–(aq). This shows that part of the students still did not learn and understand that in a protolytic process pairs of acids and bases take place, even though it has clearly been stated in the textbook and during the lectures in class.

The fourth question is, as its predecessor, a close-ended question, i.e. multiple choice question, which is of the fourth level of Bloom's taxonomy (analyzing), because the students have to analyze the provided options and make a distinction, in order to get to the correct answer. The students had to decide in which of the protolytic reactions equations, water is proton-donor. It was proven that this was one of the best answered questions even in the pre-test, whereupon the percentage of correct answers was from 53.84 % (SG, Debar) to 84 % (RG, Kichevo). This is probably due to the possibility of getting to the correct answer through the analysis of products in the reaction equation. Namely, everywhere, one of the products is H3O+, except in the correct answer, where it is just OH–. However, some students did not even bother to answer this question, whereas some others chose b), assuming that HCN is not an acid and without analyzing the reaction products in the provided equations. In the post-test, there was progress in all SGs, which is due to the animations of protolytic processes (in which water takes part) they were observing during their activities. The greatest improvement in the post-test with regard to this question was achieved by the SG in Debar (for 30.32 %) compared to the pre-test.

In the fifth question, the students had to choose which of the offered pairs responded to the pair acid/conjugated base. In the pre-test, correct answers were at about 40 %, but SG Debar had the lowest percentage of correct answers (15.38 %); however, it should be taken into account that this group also had the lowest average score of all groups. It is especially important to analyze the selection of the distracter in wrong answers. About 90 % of the wrongly-answered questions were because the students chose the distracter b).

This shows that some students were not able to make the distinction between acid/base pair and acid/conjugated base pair. In addition, this also shows that the close-ended questions can quite well reflect the students' opinions and their wrong perceptions, if they consist of smartly-thought distracters. In the post-test results, the greatest progress was noticed in the SG in Debar (for 34.62 %), whereas in the CG in Debar there was no improvement at all. We do not really have a proper explanation to this, except of concluding that by considering they have answered correctly, they have not changed their answer at all. In other CGs, the improvement in relation to the pre-test is not very big either, even though special attention was paid to these items in the revision sessions. The progress in experimental groups is due to the usage of animations which were presented to the SGs, and the questions and discussion sessions afterwards (SGs and RGs).

In the sixth question, students could earn from 2.5 to 10 points for the correct classification of each of the four particles as Brønsted acid, base or amphiprotolyte. This question can be classified in the third category of Bloom's taxonomy, because it requires partial implementation of the acquired knowledge in new situations. In fact, apart from the behavior in water solutions of some of the particles mentioned in the question, there are such which have neither been mentioned in the book, nor in teacher's lectures, e.g. HCO3–. The pre-test in all schools showed that only three students earned 10 points. The majority got 5 points by correctly classifying HBr and H2O; some others had correctly classified the sulfate anion, but almost nobody did that with the HCO3–; it has either remained unclassified or has been considered as an acid because it contains hydrogen. Due to this mode of collecting points, in all classes this pre-test question was answered correctly by about 50 % of the students. In the post-test, there were better results in all groups, though none of them could be said to have been the most successful. We expected the problem with the correct classification of the HCO3– to be resolved in the CGs, because the teacher explained the amphoteric properties of some hydrogen anions through other examples. Regardless of the improvement, the results were not that distinctive.

The seventh question was found to be the most difficult to answer and produced the worst results. The question was open-ended and it required from students to decide whether the reaction presented through the equation NH3(g) + HCl(g) = NH4Cl(s) is protolytic and to explain their answer. This question is of the higher levels of Bloom's taxonomy, namely 'evaluation'. It was expected from students, in the explanation, to know that the ammonium chloride is an ionic compound and that the ammonium ion is formed by a proton transfer from HCl to the electron pair of the nitrogen atom in the ammonia. As in all other questions which require explanation, here also, the students were not able to explain their initial answer that it is a protolytic reaction, and therefore did not provide any explanation at all. A large number of students wrote down that it was not a protolytic reaction because they considered that it is not possible for two gasses to make a solid substance! In the post-test, obvious progress could be seen with regard to this matter, especially in the RGs from all three cities, because one of the activities (Activity 3) is a direct synthesis of NH4Cl from the gaseous ammonia and HCl. The questions and discussion sessions that followed helped a lot in the improvement of results. The best result in the post-test was achieved by the RG in Kichevo (56 %), which is for 36 % higher than in the pre-test. In SG in Tetovo there was no improvement at all.

The eighth question was another open-ended question from the category 'evaluation' of Bloom's taxonomy. In the question, it is first said that some protolyte behaves as a good proton-donor and a weak proton-acceptor. This sentence has been deliberately formulated in that way, so that the students can firstly think about what it means for a substance to be a proton-donor or proton acceptor, and if the former applies, then it means that its acidic properties dominate. The following question was the next one: Can this protolyte behave as a base also? Here also, an explanation to the short yes/no answer was required. The students were supposed to answer that depending on the partner, the same substance can actually act both as an acid and as a base. This has been emphasized several times in the textbook and in teacher's presentations and we expected good results even in the pre-test. However, we found out that the pre-test results were poor, from 16.66 % (CG, Tetovo) to 30.77 % (RG, Tetovo). The greatest progress in the post-test was achieved in SG, Debar (for 30.76 %).

However, in the SG, Tetovo there was no progress at all. In fact, there were three other questions with no change in progress in both the pre- and post-test. In discussion with students, some of them said that in the post-test they had paid more attention to those questions, which they thought were related to their activities and not to those they thought that were correctly answered in the pre-test.

We were greatly surprised by the high percentage of correct answers to the 9th question even in the pre-test. The question was close-ended and it asked how the conjugated base of a strong acid would behave – as a strong or weak protolyte, or not protolyte at all. The aim of this question was to prepare students for the upcoming lesson on hydrolysis. Even in the pre-test, this question was the best answered in all three groups in Tetovo, in CG and SG in Kichevo, and in SG in Debar. The results from the post-test were slightly improved. The SG group from Debar achieved the same success in both tests, and the percentage of correct answers is high, i.e. 92.31%. However, in the SG group in Tetovo the percentage of correct answers in the post-test was lower than in the pre-test. This signaled that perhaps some of the answers were correct just by a random selection. In discussions with students, after the completion of all activities, we found out that some students had logically concluded that if the acid is strong, then its conjugated base would be a weak protolyte, and that it had also been said by the teacher.

The tenth question had to do with creativity, because students had to make a drawing of molecular models, in order to make an illustration of a weak acid solution and a column diagram in which they would show the relative concentration of particles in the solution. It was expected students to know that in a solution of weak acid, the unprotolyzed acid and conjugated acid and base are in equilibrium. This question relates to the part of the teaching material which has been titled as Protolytic equlibrium in the textbook. We were not surprised only by the low percentage of correct answers, but rather by the fact that we discovered a misconception among many students. Namely, some of the students presented a diluted solution of a strong acid instead of solution of weak acid, which means that they have these two notions, and some other students had just drawn the conjugated acid and base in the water. The percentage of correct answers to this question in the pre-test in all groups varied between 23.81 % and 38.88 %. It was discovered that in all three SG, the success had improved considerably (for about 33.13 – 38.47 %), which is due to the activity in which the student create a strong and/or weak acid solution or base, followed by a corresponding picture on the composition of the solution and the relative concentration of the particles in the solution. Better results were obtained in groups doing real experiments, distinguishing the RG from Kichevo with improvement of 48 %. This is due to activities 4 and 5 and the related questions, as well as the discussion after the completion of activities.

In order to have a clearer view on the successfulness of the three different groups, we analyzed the total results from the three schools. They are summed up in Table 3. As we can see from the results in Table 3, in general, the post-test results are better in all cases. The difference in the achievements in all three cases is statistically significant. The greatest progress though was noticed in the group which did real experiments. In addition, we wanted to check if there was a statistically significant difference in achievements in the post-test between RG and SG. It was concluded that there is a statistically significant difference in this case as well. This means that the realization of real experiments along with the questions to be answered by the students and the discussion at the end of activities produces the best possible outcomes.

The results from the comparison of answers in the pre-test and post-test for all three groups, as well as of those in the post-test between RG and SG have been given in pictures 1, 2, 3, and 4.

Table 3. Comparison of results from the pre-test and post-test for the CG and the two experimental groups, as well as the results of the post-test of RG and SG for all three groups from the three cities. The legend is the same as in Table1.

Statistical Parameter	**KG**		**RG**		**SG**		**RG-SG**	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
N	68	68	72	72	71	71	72	71
$\bar{x}$/%	44.15	54.89	43.16	64.06	39.62	56.87	64.06	56.87
s	18.94	23.86	17.29	20.78	17.43	18.13	2078	18.13
$\Delta\bar{x}$/%	10.74		20.90		17.25		7.19	
t	2.90		6.56		5.78		2.20	
$t_{cryt.}$	1.99		1.97		1.98		1.97	
p	0.0043		0.0000		0.0000		0.0300	

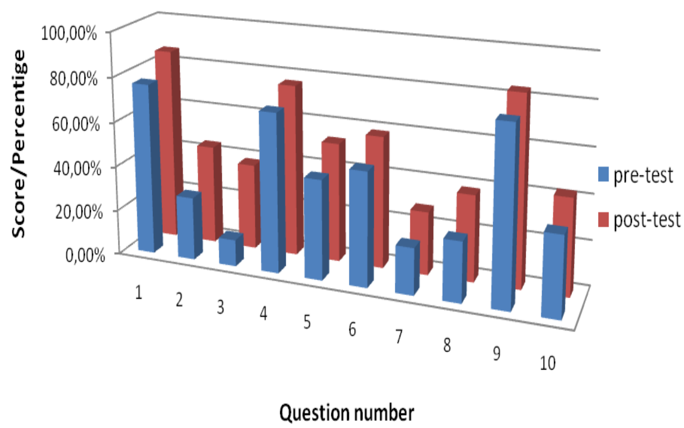

Figure 1. Comparison of the scores per each question in the pre-test and post-test for all three control groups.

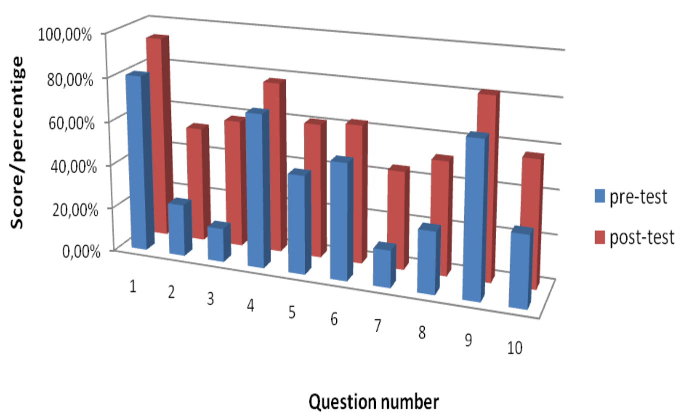

Figure 2. Comparison of the scores per each question in the pre-test and post-test for all three RG groups.

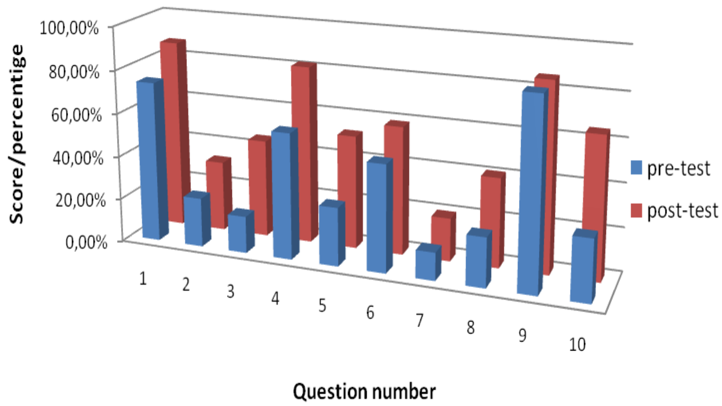

Figure 3. Comparison of the scores per each question in the pre-test and post-test for all three SG groups.

In all three groups, the worst results were obtained for questions 3, 7 and 8, i.e. in those where an explanation was needed, and the best results were achieved in questions 1 and 9. In the CG, the greatest progress, namely the biggest difference between the correct answers in the post-test and pre-test was noticed in question 3, which had to do with the proper presentation of protolytic process through equations. As regards groups which did activities with real experiments, the biggest difference between the correct answers in the post-test and pre-test was noticed in questions 2 and 7, which were related to respective experiments, whereas the greatest improvement in the group with simulative experiments and animations was noticed in responses to the 10th question.

If we compare the percentages of correct answers in the post-test between RG and SG (Fig. 4.), we can see that, in general, students in RG answered better six of the questions: 1, 2, 3, 5, 7 and 8, and the greatest difference was found for the 7th question. The greatest improvement in the SG was noticed in responses to the 10th question, which dealt with the visual presentation of existing particles of strong and weak acids in water solutions.

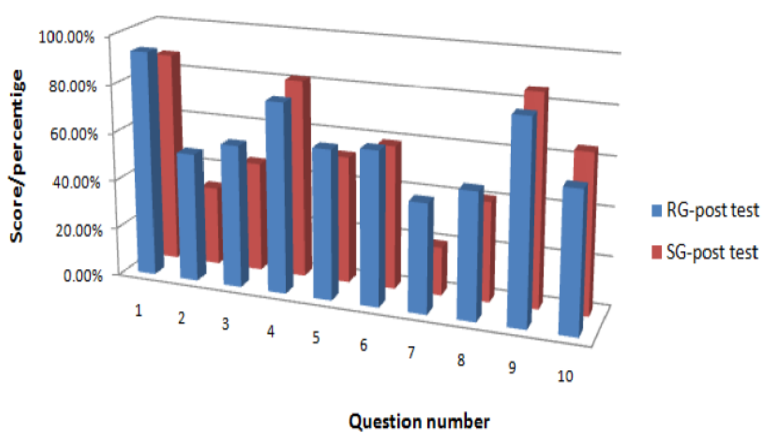

Figure 4. Comparison of the scores per each question in the post-test between RG and SG.

Conclusion

Based on this research, several conclusions can be drawn. First of all, we have to note down that the application of traditional teaching in the examined groups showed an averagely weak success (about 40 %), which can be verified with the results from the pre-test. This is because of the fact that this is quite an abstract topic with many new notions, which can be understood only if the student has good previous knowledge. In addition, there were some misconceptions that came out as a result of the pre-test (some even noticed in the literature itself). These conclusions could be drawn easily because the test itself was designed to encompass all aspects of this topic, as well as check them in relation to the higher levels of Bloom's taxonomy, which means understanding and knowledge at a higher level, having, of course, in mind the students' age.

The study showed that all three groups had better achievements in the post-test. This is due to the additional activities in all groups; however, the teaching methods that were used in the experimental groups with the aim of eliminating gaps and misconceptions, showed better results in comparison to the old traditional teaching approaches in the control group. The best results were achieved in the group which undertook real experiments. The analysis of correct answers to the questions shows that understanding the processes at a molecular level can be significantly improved by implementing appropriate computer programs and applications. In fact, both computer-based activities and real experiments would result in fruitful outcomes if they are followed by requirement students to draw conclusions by themselves and then check their understandings in a general class discussion session, whereupon final conclusions will be made. The insufficiently understood notions and concepts were also explained in the control groups, but the class was mainly controlled by the teacher himself and just a few students actively participated in class. We should also add that students in experimental groups were more motivated and interested, just because they were more actively engaged in the learning process. We have to point out that the organization of the class with active participation of students and instructions for activities planned in advance in the form of a worksheet can produce bad results too, unless all the activities and questions from the worksheet are discussed at the end, because students themselves may draw incorrect conclusions too. Just because of this, we should not go through lessons only formally and superficially, but rather, as modern education standards require, adapt and comply with the needs and achievements of the students.

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