Macedonian Journal of Chemistry and Chemical Engineering, Vol. **34**, No. 2, pp. 389–398 (2015)

MJCCA9 – 697

ISSN 1857-5552
e-ISSN 1857-5625
UDC: 373.5.091.322.7-027.22(497.7)
Education

Received: April 15, 2015
Accepted: May 26, 2015

THE COMPARISON OF DIFFERENT TEACHING APPROACHES RELATED TO THE ACHIEVEMENTS OF STUDENTS' KNOWLEDGE AND SKILLS

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This paper presents the comparative aspects of the efficiency of three different teaching approaches on the acquisition of students' knowledge and skills. The research was carried out with students (245 in total) in the second year of secondary schools from three different cities in Macedonia in relation to the topic *pH and Indicators*. In one of the groups (Control group), the traditional teaching approach was used; in the second, simulation experiments were carried out (Sim group); and in the third group, real experiments were performed (Real group). After accomplishment of the topic, a test of knowledge was implemented. The statistical analysis of the results showed that the Real and Sim groups showed better results than the Control group. Some of the questions concerning the understanding of the processes on a molecular level were better answered in Sim groups; however, in general, it was concluded that the real experiments approach was the most effective.

Keywords: acquired knowledge; teaching approaches; simulation experiments; real experiments

СПОРЕДБА НА РАЗЛИЧНИ ПРИОДИ ВО НАСТАВАТА ВРЗ СТЕКНУВАЊЕТО НА ЗНАЕЊА И ВЕШТИНИ НА УЧЕНИЦИТЕ

Во овој труд е презентирана споредба на ефикасноста на три различни приоди во наставата врз стекнувањето на знаења и вештини на учениците. Истражувањето беше спороведено со ученици (вкупно 245) од втора година гимназиско образование од три различни градови во Македонија, а во врска со темата *pH и индикатори.* Во една од групите (контролна група) беше применет традиционален приод, во втората беа изведувани симулациски експерименти (сим–група), а во третата група беа изведувани реални експерименти (реал–група). По завршувањето на активностите од темата беше спроведен тест на знаење. Статистичката анализа на добиените резултати покажа дека реал–групите и сим–групите покажаа подобри резултати од контролната група. Прашањата кои се однесуваа на разбирањето на процесите на молекуларно ниво беа подобро одговорени од сим–групите. Но, може да се заклучи дека наставата со реални експерименти беше најефикасна.

Клучни зборови: стекнување знаења; наставни приоди; симулациски експерименти; реални експерименти

1. INTRODUCTION

Chemistry is one of the most important disciplines of science and technology. It connects the processes in the so called "macro-world" with the phenomena at the molecular level responsible for these processes. Chemistry education is therefore deeply related to the experiences of everyday life, observations and experimental or practical facts. Chemistry curricula commonly incorporate many abstract concepts, which are central to further learning in both chemistry and other sciences [1]. These abstract concepts are important because further chemistry/science concepts or theories cannot be easily understood if these underpinning concepts are not sufficiently grasped by students [2–5].

At the beginning of any course, students start their study with a set of beliefs about the nature of learning and what they intend to achieve [6]. These beliefs are derived from earlier school and learning experiences, as well as their current goals and motives. An understanding of how students learn can help teachers to devise effective strategies for teaching, and the best methods, approaches and techniques for particular teaching units.

In recent years, there have been many studies related to the problems of teaching chemistry, especially of application of computer-based learning (CBL). In many studies, CBL showed some benefits, but there were some cases in which no benefits were observed. One of the first studies related to this problem was that of Ybarrondo [7], who attempted to determine whether the application of CBL in high school biology classes would increase the level of understanding concepts. However, the results comparing the experimental group in which the CBL was applied and the control group in which traditional teaching methods was performed, showed no significant differences. Two years later, Gerardo compared the effectiveness of technology-assisted teaching with the traditional method and found that the students were more successful in technology-assisted teaching [8]. A similar investigation was performed by Jackman [9], with a group of freshmen university students using the computer simulations on spectrophotometry. It was shown that the CBL group had better post-test results than the group that was taught traditionally. Jackson was studying the effects of applying computer technologies on the attitudes, motivation and studying, but also on using computer-assisted tests [10]. The investigation was performed with the students of secondary school divided into two groups: control and experimental. The statistical evaluation showed higher achievements of the experimental group who used CBL.

The literature search clearly showed that with development of the informatics technology, increasingly more sophisticated computer-based applications were accessible for the teacher and students. Thus, Demirel [11] has pointed out that computer programs can be used for one-to-one instruction, revision, and simulation, but also for problem solving. Demircioğlu and Geban compared CBL with the traditional teaching method on sixth grade students in science classes [12]. Again, the students were divided into an experimental group taught with CBL and a control group taught traditionally. The science achievement rates of the two groups were compared through a *t*-test and the group that was taught through teaching methods applied by computer applications was found show more success. A similar comparison study was conducted by Ertepõnar [13], involving logical thinking skills for high-school chemistry. It was clearly shown that the computer-assisted method was much more successful in developing logical thinking and consequently the achievements of the students were better in comparison to those of the control group.

In the last decade, a number of computer software packages for experimental simulations have been developed and now form part of many computer learning packages. These programs offers studying and understanding of many phenomena which could not be investigated experimentally in the classroom due to their associated hazards, long duration, high cost, etc. [14, 15]. According to Barbour and Reeves [16], this kind of education technology provides advanced individualized learning and a high level of flexibility and freedom for time and location constrains. Gorghiu *et al.* studied challenges and successes in studying chemistry using simulation experiments [17, 18]. In this paper, the authors presented the software package *Crocodile Chemistry* for designing simulation experiments used in teaching chemistry. Also, some reports on new software for chemistry education were presented. Thus, Demigraç *et al.* [19] developed software for computer-assisted education material related to thermochemistry and investigated its effectiveness on the students' success. The data obtained from the performed tests were analyzed by using statistical programs. The results of the analysis indicated that computer-assisted education methods have more of an effect on students' chemistry success, and attitudes towards chemistry than traditional method.

According to the literature data, almost all papers dealing with CBL present research in which introducing simulation experiments methods is compared with traditional teaching. However, just a few examples of literature data were found which compared traditional teaching, CBL with simulation experiments and teaching with real experiments. Sönmez [20] and more recently Bayramlı [21] have pointed out that the method of real experiments stimulates more sensory organs and attracts the attention of the students. Sample event method makes the students aware of real life problems. By implementing the principles and concepts which were previously learnt, the gaps between theory and practice are filled. The greatest benefit is that this helps students to implement what they know and have conceived in lessons in real situations; it makes students more active during the lessons. Most recently, William *et al.* [22] designed and trialed integrated chemistry modules. The observations showed that teachers and students appreciated the approach. It was therefore concluded that video materials, classroom experiments and worksheets can assist students in attaining the required competencies.

Taking into consideration the literature data search, we think that it is important to make a comparison of three approaches: traditional, those with simulated experiments and those with real experiments, in order to determine the specific benefits and how to combine them to obtain the best results in students' achievements in chemistry. For this purpose, we have chosen the unit *pH and indicators*, which is a part of the topic *Protolytic Processes.*

The investigation of *Acids and Bases* for secondary school students has been provided by Morgil *et al.*, but their work simply compared CBL and traditional learning [23]. Sheppard applied a series of qualitative and computer-based tasks to examine the understanding of titrations and acid-base contests [24]. The findings indicated that students had considerable difficulty with acid-base chemistry, and were unable to accurately describe acid-base concepts, such as pH, neutralization, strength, and the theoretical descriptions of acids and bases. A number of factors were identified as contributing to these difficulties, including the overstuffed nature of introductory chemistry itself, the emphasis during instruction on solving numerical problems and the dominant role played by textbooks.

Since there are no literature data comparing the efficiency of three different teaching approaches (traditional, with real experiments and with simulated experiments) on the acquisition of students' knowledge and skills related to pH and indicators, we have done such investigation and the results are presented below.

2. EXPERIMENTAL

2.1. *Methods and samples*

2.1.1. *The samples*

The investigation of the efficiency of three different teaching approaches (traditional, with real experiments and with simulated experiments) on the achievements of the students was performed in three classes of second grade students (age 15–16) of Secondary School (High School) in three cities in Macedonia (Tetovo, Debar and Kičevo) on the teaching unit *pH and Indicators*. Two experimental groups and one control group were formed. In total, 245 students were included in the investigation. In one of the experimental groups, computer simulations were included during teaching and we will refer to this group as the Sim group. In the other group, real experiments were performed during teaching and we will refer to this group as the Real group. The teaching of the Control group was performed without any experiments, and simply involved the teacher presenting the facts. In order to obtain the most objective results possible, the three classes from the same school were of similar average scores in chemistry, but pre-testing for general chemistry knowledge was also undertaken.

2.1.2. *Students' activities*

For this investigation, the teaching unit *pH and Indicators* was performed in three teaching lessons. The first was the same for all three groups; in this lesson, the teacher gave the theoretical basics for the unit *pH and Indicators* and also some numerical problems on pH were solved. The second lesson was different for all three groups: the students from the Control group were left to discuss and solve numerical problems on pH and neutralization, while the students from the Real group and Sim groups were engaged in defined activities. The active experimentation in the Real group was performed with the students divided into five groups, each consisting of five to six students. Each group had to accomplish different experiments related to pH and indicators. The experiments were simple and connected with everyday life, but gave insight into abstract chemistry concepts. After finishing the activities the students presented the results and discussed them. The activities of the Real group are given in Supplementary Materials I.

The students in the Sim group were divided into pairs. They used the *Crocodile Chemistry* software package [25] to design simulation experiments of a given task. Also, they watched animations of the processes of water protolysis and neutralization processes. After they had finished the activities, they had a discussion about the results. The activities of the Sim group are given in Supplementary Materials II.

The third lesson was the same for all three groups; namely, they were tested for their acquired knowledge on pH and Indicators.

2.2. *About the test*

The acquired knowledge was measured by means of conceptual test after the performed lessons. The chemistry achievement test was prepared according to the taxonomy of Bloom. Taxonomy for educational purposes, known as Bloom taxonomy, presents the classification of different learning goals [26]. The taxonomy improved version, used in this investigation [27], was published in 2001 entitled "Taxonomy for learning, teaching and assessment". According to the new taxonomy of Bloom, questions are prepared on several levels: 1) Remembering 2) Understanding 3) Applying 4) Analyzing 5) Evaluating and 6) Creating. Like other taxonomy, in the Bloom taxonomy there is also a hierarchy, which means that higher levels of teaching depend on the knowledge and skills acquired in previous lower levels.

The test performed with each of the studied groups consisted of fifteen conceptual questions. Ten of them were multiple-choice questions, two were numerical problems, two questions were of one specific answer and one question was on table construction. The questions were chosen such as to show the achievements related to theory, problem solving, understanding the processes at the molecular level and on a practical and applicative level. The total number of points was 65. The test is shown in Supplementary Materials III.

3. RESULTS AND DISCUSSION

As mentioned previously, the students of each of the three groups were of the same average pre-knowledge according to their grades for chemistry and the results of the pre-test. Therefore, we assume that the results obtained for the test performed after completion of the teaching unit *pH and Indicators* by the three different applied approaches could give a realistic picture of their efficiency of acquiring knowledge.

The statistical analysis and comparison of the results obtained by the test performed within the three groups of students in three cities in Macedonia was done using the statistical package *Statgraph* [28]. The results are summarized in Tables 1–4. The comparison of the results between the Sim and Control groups is given in Table 1. It can be seen that in all three schools, the average test score of the Sim groups was better than that of the Control groups, and the most pronounced difference between the average score of the Sim and Control groups was observed between the students of Debar Secondary School. In all three cases, the calculated *t*-test showed that the difference in the average score was statistically significant (the value of t was higher than $t_{cryt.}$ and p was lower than 0.05).

Table 1

The statistical evaluation and comparison of the result obtained for the Sim and Control groups

Statistical parameter	Tetovo		Kičevo		Debar	
	Sim	Control	Sim	Control	Sim	Control
N	26	28	27	26	29	27
$\overline{x}$	44.42	36.43	45.44	37.13	46.55	33.17
$\overline{x}$ (%)	68.38	56.09	69.90	57.12	71.61	51.03
s	14.39	14.40	13.56	11.39	12.55	15.62
$\Delta\overline{x}$ /%	11.37		12.78		20.58	
t	2.04		2.45		3.52	
$t_{cryt.}$	2.01		2.01		2.01	
df	52		50		50	
p	0.0465		0.0179		0.0009	

Designation: N – number of students; $\overline{x}$ – average score; s – standard deviation; $\Delta\overline{x}$ – difference between average score; t – t-test; $t_{cryt.}$ – critical value of the t-test; df – degrees of freedom; p – p-value.
These designations are the same for the other three tables.

The average score of the Real groups was even better and consequently the differences in the scores related to the Control groups (Table 2). Also, the difference between the average score of the Real and Control group in each case was statistically significant.

Table 2

The statistical evaluation and comparison of the results obtained for the Real and Control groups

Statistical parameter	Tetovo		Kičevo		Debar	
	Real	Control	Real	Control	Real	Control
N	27	28	29	26	26	27
$\overline{x}$	46.85	36.43	51.03	37.13	50.00	33.17
$\overline{x}$ /%	72.09	56.06	78.51	57.12	76.92	51,03
s	11.47	14.40	8.01	11.39	9.01	15.62
$\Delta\overline{x}$ /%	16.03		20,14		25.89	
t	2.96		5.16		4.49	
$t_{cryt.}$	2.01		2.01		2.01	
df	51		45		44	
p	0.0047		0.0000		0.0000	

However, although comparison of the achievements of the Real and Sim groups showed that the average score of Real group was better than that of the Sim group, the difference was not statistically significant in all three cases (Table 3).

Table 3

The statistical evaluation and comparison of the results obtained for the Real and Sim groups

Statistical parameter	Tetovo		Kičevo		Debar	
	Real	Sim	Real	Sim	Real	Sim
N	27	26	29	27	26	29
$\overline{x}$	46.85	44.42	51.03	45.44	50.00	46.55
$\overline{x}$ /%	72.08	68.34	78.51	69.91	76.92	71,61
s	11.47	14.39	8.01	13.56	9.01	12.55
$\Delta\overline{x}$	2.43		5.57		3.45	
$\Delta\overline{x}$ /%	3.74		8.57		5.31	
t	0.66		1.88		1.16	
$t_{cryt.}$	2.01		2.02		2.01	
df	48		42		51	
p	0.5135		0.0665		0.2488	

Finally, in order to obtain an even better picture for the achievements of students taught by three different approaches, a statistical evaluation was performed taking into account the sum of the scores of the total number of students from three different cities in Macedonia (Table 4). As can be seen from Table 4, there was a statistically significant difference between the achievements of the Real and Control and the Sim and Control groups. However, in this case, there was also a statistically significant difference between the average scores of the Real and Sim groups.

Table 4

The statistical evaluation and comparison of the results obtained for the Real, Sim and Control groups taking into account the total number of students from all three cities

Statistical parameter	Total					
	Sim	Control	Real	Control	Real	Sim
N	82	81	82	81	82	82
$\Delta\overline{x}$	45.51	35.57	49.29	35.57	49.29	45.51
$\Delta\overline{x}$ /%	70.01	54.72	75.83	54.72	75.83	70.01
s	11.47	13.88	9.63	13.88	9.63	12.55
$\Delta\overline{x}$ /%	15,29		21,11		5.82	
t	4.67		7.32		2.09	
$t_{cryt.}$	1.97		1.98		1.97	
df	160		142		148	
P	0.0000		0.0000		0.0384	

Taking into consideration the general test scores, it could be concluded that the students taught by computer simulations and real chemical experiments have an advantage over the Control group in which traditional lessons were carried out. It must be pointed out also that it was obvious during teaching by simulation and real experiments that the students' motivation and positive attitude towards chemistry had been increased.

The analysis and discussion of the scores for each question is also very important (Fig. 1, 2, 3 and 4). The first three questions are of the lowest Bloom taxonomy level – remembering. The first question in the test is related to the knowledge of the students on the definition of the potential of hydrogen, the second to the definition of indicator, while the third is related to the measurement of pH. The students were expected to show similar achievements since these questions are not related to experiments. For these three questions, the differences in the scores between the Control, Sim and Real groups were not so pronounced. Thus, the first question was best answered by Sim group students from Tetovo and Debar, but by the Real group from Kičevo. The lowest average score was obtained in the Control group of Debar (65.38 %), and the best score in the Real group of Kičevo (89.66 %). The students of the Control group from Tetovo and Kičevo showed better results for the second question than the students from the Sim and Real groups. The students from the Real group of Debar showed the best score for the second question (96.20 %) and the most significant difference to the score of the students from the Control group (65.38 %). The third question was answered with very high and similar average scores by all three groups in each of the cities.

Questions 4–9 are of the second Bloom taxonomy level – understanding. The fourth question is related to understanding the process of neutralization and it asks to recognize the equation of the process of neutralization (Supplementary Materials III). All three groups from Kičevo showed similar results, but the students in the Real groups from Tetovo and Debar showed better scores than the Sim and Control groups from those cities. The most significant difference could be observed between the Real (92.31 %) and Control (65.38 %) groups in Debar.

The fifth question is connected to understanding the relation between pH-value and the concentration of H_3O^+ ions. Of course, this question could be correctly answered if the theory is well taught, but the simulations and especially the real experiments are very helpful. Thus, one of the activities in the Real groups (Activity 2, Supplementary Materials I) is pH measurements of different solutions from everyday life and calculation of the concentration of H_3O^+ ions. Indeed, the average scores of the Real groups from all three cities were much better than those from the Sim and Control groups. Actually, this is the only question with a score of 100 % (Fig. 3).

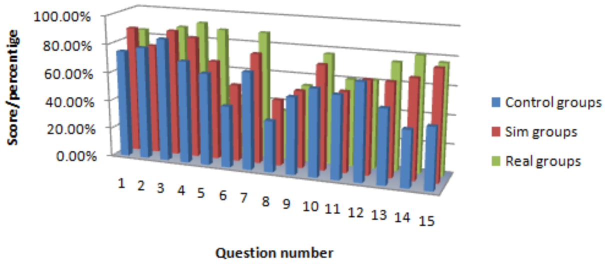

Fig. 1. Comparison between the average score for each question of the Control, Sim and Real groups from Tetovo

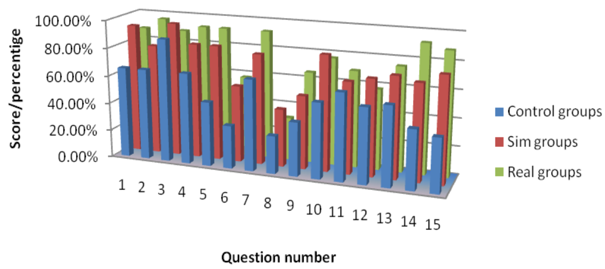

Fig. 2. Comparison between the average score for each question of the Control, Sim and Real groups from Debar

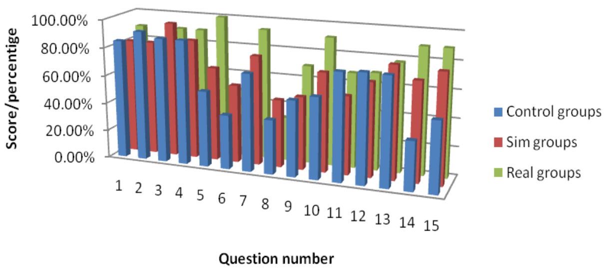

Fig. 3. Comparison between the average score for each Question of the Control, Sim and Real groups from Kičevo

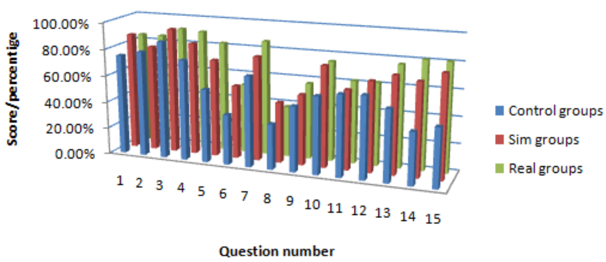

Fig. 4. Comparison between the average score for each Question of the Control, Sim and Real groups from Tetovo, Kičevo and Debar

As expected, the most frequently selected incorrect answer was the distracter C, which offers the highest pH value of all other distracters. This points out that some of the students do not understand the mathematical relationship between the concentration of H_3O^+ ions and pH value and simply think that the highest value of pH is related to the highest concentration of H_3O^+ ions.

The sixth question is related to the temperature dependence of pH. It asks for the pH of pure water at 55 °C. Although this is explained in the textbook, the results showed that this question was one of the most difficult for the students and therefore gave a low average score. However, again, the Real groups had better scores since activity 4 was directly connected to the requirement in the question. The highest score was observed in the Real group from Debar (57.69 %). The seventh question appeared an easy question, particularly for students of the Real group. Namely, the aim of the seventh question is about the changing color of the indicator phenolphthalein in an appropriate pH range. Both the Sim and Real groups showed better scores than the Control group since some of the activities were related to this problem. Thus, the Sim groups observed simulations of color changes of phenolphthalein in basic solutions (Activity 2, Supplementary Materials II) and the Real groups performed experiments with phenolphthalein in acid and base solutions (Activity 1 Supplementary Materials II). The highest score was observed for the Real group from Tetovo (93.10 %) and the lowest (65.38 %) for the Control group from Debar.

The most difficult question with the lowest average score was the eighth question. Thus, the highest score was observed in the Sim group from Kičevo (48.15 %), and the lowest score in the Control group from Debar (26.92 %). This question asks how the concentration of the H_3O^+ ions will be affected if the pH is changed from 6 to 3. The aim of the question is to check whether the students understand the relationship between the pH and the concentration of H_3O^+ in real mathematical manner. Although many students knew how to calculate the concentration of H_3O^+ ions at pH = 6 and pH= 3, they did not give the correct answer. Many of the students chose the distracter A, *i.e.* that $c(H_3O^+)$ will increase by three times; they knew that the concentration of H_3O^+ ions would increase when the pH decreased but they did not have an idea or did not know to calculate the ratio of $c(H_3O^+)$ at two different pH values. Some of the students thought that the $c(H_3O^+)$ ions would decrease when the pH decreases, which means that they do not in fact understand the concept of pH.

The ninth question is also very important as it aims to assess whether the students understand the protolytic reactions related to pH changes. It was expected that the students of the Real and Sim groups would achieve better scores in comparison with the Control group since one of the experiments performed (Activity 5, Supplementary Materials I and Activity 3, Supplementary Materials II) is related to this problem. However, the scores for all three groups of students from Tetovo were almost the same (approximately 55 %), with the students in the Sim group from Debar showed somewhat better scores than the students of the Control and Real groups. The students in the Control and Sim groups from Kičevo showed almost the same score, but the achievements of the students in the Control group were better and gave the best score for this question (69.83 %). The most frequently chosen incorrect answer was distracter A. Actually, the students knew that acids donate protons in water solutions and the pH decreases, but they did not take into consideration the fact that this question presents the process of neutralization. It is interesting to mention that some students answered the fourth question correctly, which was related to the process of neutralization, but gave an incorrect answer to this question, while other students answered this question correctly but did not know what the effective ionic reaction of the process of neutralization is.

The tenth question is from the third level of Bloom's taxonomy (application), since it is related to practical problems on the basis of the theoretic pre-knowledge that the pH value is related to the concentration of H_3O^+ ions. The question asks how the pH of an acid solution could be increased. As expected, the students in the Real groups showed better scores in comparison with the students in the Sim and Control groups since they carried out an activity related to this problem (Activity 3, Supplementary Materials I). The highest average score was observed in the Real group from Kičevo (91.03 %) and the lowest was in the Control group from Debar (53.85 %).

The last five questions were not multiple choice (Supplementary Materials III). The eleventh and twelfth questions were also of the third category of Bloom's taxonomy and are related to application of the gained knowledge in order to solve numerical problems. The eleventh question consists of two numerical problems that require pH calculations knowing the concentration of H_3O^+ ions (a) and the concentration of OH^- ions (b). The twelfth question is the opposite of the eleventh – calculation of the concentration of H_3O^+ ions on the basis of the pH of a solution. These questions are not directly connected to the application of real experiments and simulations. Therefore, the scores of all three groups were very close and even the Control group of Kičevo showed better results than the two experimental groups for both questions, and the Control group of Tetovo also showed better scores for the twelfth question. It is interesting to point out that the students who did not answer the first question (the mathematical expression of pH) correctly failed to answer these two questions also. The analysis of the results of the test in general also showed that the students sometimes answered some of the questions in a schematic way only (*e.g.* if the pH = 3, the $c(OH^-) = 10^{-3}$ mol/l, *etc.*) without a basic understanding. This explains why some of the students gave a correct solution for 11a, but were not able to solve problem 11b. Since these two numerical problems were of the open type, the answers were taken as correct only if the entire procedure of solving the problem, including the units of the quantities, were correct.

The thirteenth and fourteenth questions were of the fourth Bloom's level – analyzing. In the thirteenth question the students had to analyze four pictures presenting chemical processes with molecular models. The students were asked to recognize each of the processes. This question is important since it checks whether the students understand what is happening on a molecular level. Within the activities of the Sim groups, the animations of the processes on the molecular level were incorporated and students were asked to observe the animations. Therefore, it was expected that these groups would show the best scores. However, this was the case in Kičevo, but in Tetovo and Debar the Real groups showed better results than the Control and Sim groups. Except in Kichevo where all three groups showed comparable results, the Control groups of Tetovo and Debar showed significantly lower scores than the Sim and Real groups.

The fourteenth question is related to real experiments (Activities 2, Supplementary Materials I) and to simulated experiments activities (Activity 2, Supplementary Materials II). The students had to analyze the colors of a universal indicator in six different solutions and were then asked to complete a table in which they ranged the solutions and pH values from the most to the least acidic, *e.g.* most basic. As expected, the best scores were reported for the students from the Real groups in all schools and the average scores were very high, namely, around 90 %.

The last question was of Bloom's fifth taxonomy level, *e.g.* evaluating, since the students had to evaluate which of the three natural indicators is best for the neutralization of a strong acid with a strong base according to the color change. Again, the best scores were shown for students from the Real groups which performed similar experiments (Activity 5, Supplementary Materials I). It should be mentioned that the students from the Control groups showed significantly lower scores.

The total scores of the three groups from Tetovo, Debar and Kičevo are summarized in Figure 4. This is the most relevant picture since the scores of 245 students were taken into account. As can be seen from Figure 4, the Real group scores were the best for the 2nd, 4th, 5th, 7th, 9th, 11th, 13th, 14th and 15th questions and the highest scores were shown for the 1st, 3rd, 6th, 8th and 10th and 12th questions in the Sim group. However, for some of the questions (1, 2, 3, 4, 8, 11 and 12), the scores for all three groups were close to each other. On average, the eighth question yielded the lowest score of all questions. The most significant difference between the scores obtained was seen for question 14: the average score of the Real group was 81.17 % and of the Control group was 38.78 %. Also, the difference in the scores for the Real (81.04 %) and Control (43.79 %) group was significant.

4. CONCLUSIONS AND SUGGESTIONS

This research shows that there is a significant difference between the knowledge acquired through learning supported by real experiments and by computer simulated experiments in comparison to the traditional route. However, both of the approaches gave different contributions, depending on the features they possess. Of course, there is some overlap in developing collaborative and team skills, but there are also differences. For example, students in the Sim group did not spend time on experimental activities and problems related to techniques and manual work, but they could spend more time on analyzing, discussing and observing animations, which was helpful to better understand the phenomena on a molecular level. On the other hand, the students of the Real groups were asked not to just perform and observe real experiments but also to extract conclusions from their observations, which require engagement in the problem and applying a higher level of thinking. It must be pointed out that, in general, the scores of the Real groups were the best, particularly in comparison to the Control group.

Although for some questions of the test, the Control group showed better scores than the Real and Sim groups, the total score was significantly lower. This is probably due to the fact that all students, at every moment, were not active participants in the process of learning and were therefore less motivated.

Finally, the teacher should be the final filter and corrector. He/she is the person who should ultimately decide which approach to use, based on the situation in the classroom, the objectives to be fulfilled and the concepts which should be mastered.

Through the findings of this study, we can suggest that the best teaching approach for the topic *pH and Indicators* is the combination of real experiments and computer animations. As mentioned, the animations are very helpful for visualizing and understanding the phenomenon on a molecular level, but whenever possible, real experiments guided by a proficient teacher should be performed, since they are the most powerful didactical tool in chemistry.

Similar applications can be conducted related to other chemistry subjects. Teaching materials and curricula should be developed in order to provide an opportunity for new teaching approaches and methods, particularly implementing computer simulations besides real experiments. A rich learning environment should be provided to ensure using a new teaching method effectively.

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Supplementary Materials III

The test

1. The potential of hydrogen (pH) is defined as:

   a) pH = $c(H_3O^+)$

   b) pH = -log$c(H_3O^+)$/mol·dm^{-3}

   c) log pH = $c(H_3O^+)$

   d) $c(H_3O^+) \cdot c(OH^-) = K$w

   e) $c(H_3O^+) = K$w / $c(OH^-)$

   (Remembering; 2 points)

2. The indicators:

   a) are strong inorganic acids.

   b) are colourless liquids.

   c) have same color in acidic and basic solutions.

   d) change their color according to the relative concentration of H_3O^+ and OH^- ions.

   e) are strong inorganic bases.

   (Remembering; 2 points)

3. The precise measurement of pH could be done by:

   a) litmus paper

   b) phenolphthalein

c) pH-meter

e) ionometer

d) methyl orange

(Remembering; 2 points)

4. Which of the equations listed below describes the process of neutralization:

a) Fe + S = FeS

b) $H_3O^+(aq) + OH^-(aq) = 2H_2O(l)$

c) $2NaCl + H_2SO_4 = Na_2SO_4 + 2HCl$

d) $Cu^{2+}(aq) + 2OH^-(aq) = Cu(OH)_2(s)$

e) $As_2S_3 + 6H_2O = 2H_3AsO_3 + 3H_2S\uparrow$

(Understanding; 4 points)

5. In which of these solutions, $c(H_3O^+)$ has the highest value?

a) Blood, pH = 7.42

b) Lemonade, pH = 2.91

c) Shampoo, pH = 9.21

d) Tea, pH = 3.94

e) Tomato puree, pH = 4.32

(Understanding; 4 points)

6. If the temperature of pure water is 55 ^{o}C, the pH value of pure water will be:

a) 7

b) below 7.

c) above 7.

d) below 10^{-7} mol/L.

e) above 10^{-7} mol/L.

(Understanding 4 points)

7. The solution of phenolphthalein is colourless, but in pH = 8-10 it turns to violet. In which of these solutions phenolphthalein will turn to violet?

    a) slightly to medium acidic
    b) neutral
    c) strongly acidic
    d) slightly basic
    e) very strongly basic

    (Understanding; 4 points)

8. If the pH value of a solution changes from 6 to 3, how the concentration of H_3O^+ ions changes?

    a) The concentration of H_3O^+ ions will increase by three times.
    b) The concentration of H_3O^+ ions will decrease by three times.
    c) The concentration of H_3O^+ ions will be the same. Just the pH is changed.
    d) The concentration of H_3O^+ ions will increase by thousand times.
    e) The concentration of H_3O^+ ions will decrease by thousand times.

    (Understanding; 4 points)

9. In a solution of acetic acid, a solution of sodium hydroxide is added. What kind of process occurs and how the pH value changes?

   a) Acetic acid donates protons and the pH decreases.

   b) Acetic acid donates protons and the pH increases.

   c) Acetic acid accepts protons and the pH increases.

   d) Acetic acid accepts protons and the pH decreases.

   e) The pH value does not change at all.

   (Understanding; 4 points)

10. The pH of a solution of an acid is 3. What would you do to change pH = 3 to pH = 5?

    a) Evaporate the water until pH = 5.

    b) Add some amount of the same acid.

    c) Add water until pH = 5

    d) Add some amount of weak acid.

    e) Change the indicator.

    (Applying; 5 points)

11. Calculate pH of solutions where:

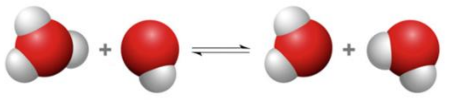
a) $c(H_3O^+) = 1 \cdot 10^{-4}$ mol/dm^3 and b) $c(OH^-) = 10^{-8}$ mol/dm^3

[Applying, 5 points in total: a) 2 and b) 3 points]

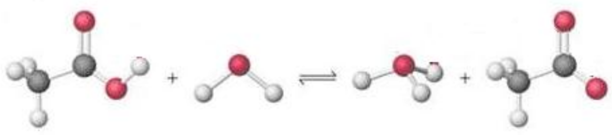
12. Calculate the concentration of H_3O^+ ions in a solution if pH is 6?

(Applying, 5 points)

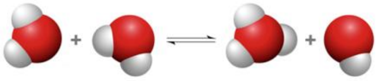
13. On the line bellow each picture write down the type of the process and the corresponding pH value or pH range.



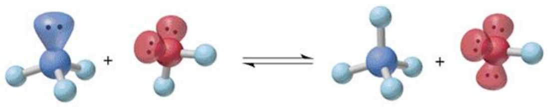
a)________________________________



b)________________________________



c)________________________________



d)________________________________

(Analysing, 6 points in total)

14. A scientist is given 6 solutions labeled A to F. The scientist tests each solution with universal indicator and records the results as follows:

Solution	A	B	C	D	E	F
Colour of universal indicator	Yellow	Blue	Green	Red	Purple	Orange

Arrange the solutions in order from most acidic (at the left) to most basic (at the right) in the table below, the colour and the approximate pH range of each solution in the table.

Solution						
Colour of universal indicator						
pH range						

(Analysing, 6 points)

15. The table below shows three natural indicators and the colours they will have at different pH values.

Indicator	Colour in acid (pH < 7)	Colour at pH = 7	Colour in base (pH > 7)
Red cabbage water	red, pink	purple	blue, green, yellow
Red onion water	red	violet	green
Turmeric water	yellow	yellow	red

Decide which indicator is the best to show you that you have completely neutralized a solution of HCl with solution of NaOH.

(Evaluating; 8 points)