The New Educational Review

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Contribution of Student and Demonstration Experiments to the Quality of Students' Knowledge about Matter in the Initial Chemical Education

Abstract

The aim of the paper is to determine whether there is a difference in student knowledge at all cognitive levels when the content about physical-chemical properties of matter are taught with the use of demonstration and student experiments in the third grade of primary school. Research sample consisted of 142 students. Experimental, comparative and descriptive – analytical methods were used. The survey instrument was a test. The students who had independently performed experiments obtained better results at the cognitive level of analysis, synthesis and evaluation on the final test and retest than the students to whom experiments had been demonstrated by the teacher.

Keywords: *demonstration experiments, initial chemical education, student experiments, student knowledge of physical-chemical properties of matter.*

Intraduction

Primary school students learn chemical content through the integrated content of science. In the education system of the Republic of Serbia students learn the integrated content science through the *World around us* compulsory subjects (the first and the second grade – aged from 7 to 9) and *Nature and Society* (the third and the fourth grade – aged from 9 to 11). In the initial chemistry education it is important to enable students to observe (Ahtee, 2009), directly or indirectly, certain natural processes and phenomena (Agranovich, 2013; Lamar, 2012). The observations can be implemented in two forms (observation is studying objects or phenomena that are in their natural state and observation in experimental conditions). Demonstration experiments are appropriate when students do not have more distinct notions about experiments and how they should be performed, and when a lot of time must be spent if the experiments are performed by students. Experiments should be demonstrated when they are complicated for students' age, as well as relatively dangerous for the students. The teacher should perform experiments in situations where the effect of demonstrations is more striking than the effect of student experiments. They must also draw students' attention to the demonstrated phenomena or give them an idea of what they should observe during the experiment. In most cases student experiments are simpler than demonstration experiments. These experiments enable all students in the class to be systematic and thoroughly introduced to experimental techniques. Students' interest is greater when they perform experiments themselves, because they look forward to what will happen in the experiment, whether the experiment will succeed, etc. Unsuccessful student experiments do not have a negative impact on students, but on the contrary, they motivate them to examine the causes of the failure in order to remove them and then re-perform the experiment in specific directions (Bognar, 2012).

Demonstration and student experiments contribute to the rationalization of time and they can sometimes be used as a means by which questions will be asked to students. Through demonstration and student experiments students develop scientific research spirit, experimental skills and knowledge are developed and children are motivated to study the physical and chemical content (Cvjeticanin, Segedinac and Sucevic, 2011). Demonstration and student experiments must be simple, and the conditions in which they are performed easily explainable to students (Kirikkaya, 2011). When selecting experiments, what must be taken into account is that the experiment should be: methodologically appropriate (meaning that students must come to correct conclusions), methodologically correct (comprehensible, clear and convincing) and methodologically required (without the experiment students would not be able to reason, think or reach a particular conclusion).

Research methodology

The research aim was to determine whether there is a difference in student knowledge at all cognitive levels (cognitive levels identified by Bloom) when the content about physico-chemical properties of matter are taught with the use of demonstration and student experiments in the third grade. The main hypothesis was: Demonstration and student experiments have the same impact on the quality of third grade student knowledge about physical-chemical properties of matter at all cognitive levels. Demonstration and student experiments help achieve high quality knowledge of the physical-chemical properties of matter. The independent variable in the research was learning with the use of demonstration and student experiments. The dependent variable was the quality of student knowledge at different cognitive levels. The measure for this variable was the score at each cognitive level on test (on final test and retest).

Experimental, comparative and descriptive-analytical methods were used in the research. The research technique was testing, and tests (initial, final and retest) were used as a measuring instrument. Each test consisted of 12 tasks which evaluated the six levels of knowledge: the level of information recall (knowledge), the level of comprehension, the level of application, the level of analysis, the level of synthesis and the level of evaluation. At each cognitive level students had two tasks. Test questions for various cognitive levels were taken from Smart tasks (Walker, 2004) and were used in the design of tasks on materials. When analyzing the level of knowledge, two tasks types, i.e. defining terms and marking drawings, were used. For the analysis of the level of comprehension, tasks of making order, drawing and filling in were used. Tasks like making a connection to personal experience, preparation of knowledge in order to change the current situation, the use of other sources of information and finding errors were set for the analysis of the level of application. The level of analysis examined another types of tasks: identifying similarities and differences; determination; classification and tasks of expressing one's attitude. Tasks to identify the strengths and weaknesses, e.g. questions like: '*what would happen if…*' and reasoning tasks that were applied in the analysis of the synthesis level. For the level of evaluation, tasks like the interpretation of a drawing were applied. When evaluating the tasks, the rule that tasks requiring higher levels of knowledge have a higher score was applied. The students worked on each test during one school lesson. When analyzing the results the following statistical parameters were used: mean test score, the percentage of obtained scores in relation to the maximum possible, the standard deviation (SD) and coefficient of variation (CV). The statistical significance of the obtained differences between arithmetic means was determined by analysis of variance (ANOVA) or t-test, and for further comparison the least significant difference test (LSD, significant at 1% and 5%) was given.

The sample comprised 142 third-grade students (71 in E group and 71 in D group). The percentage of the students that had particular overall success and particular success in the *Nature and Society* subject at the end of the first semester, as well as average mark of all the students in group are shown in Table 1. The average mark of the overall success of the students is similar for both groups. Similar data was obtained when analyzing the success of the students in D and E groups in the *Nature and Society* subject.

Table 1. Research Sample, the overall success of the students and the success in the *Nature and Society* subject at the end of the first semester

Group	Student gender		Overall success in the first semester						Success in the *Nature and Society* subject					
			% of students with mark					Average mark	% of students with mark					Average mark
	M	F	excellent	very good	good	Satisfactory	poor		excellent	very good	good	Satisfactory	poor	
E	34	37	22.5	26.8	38.0	7.1	5.6	3.53	32.4	19.7	33.8	11.3	2.8	3.68
D	31	40	23.9	28.2	33.8	9.9	4.2	3.58	31.0	21.1	35.2	5.7	7.0	3.77
Σ	65	77	23.2	27.5	35.9	8.5	4.9	3.56	31.2	20.4	34.5	8.5	4.4	3.73

The experiments that were implemented in the D and E groups were the same. They included the content about the physical-chemical properties of matter and were carried out during three weeks (six classes). Two experiments were performed per each class, on average. They were basic (used in acquiring knowledge of the students about the basic physical-chemical properties of matter) and parallel (the comparison of properties of different states of matter). One week before doing the experiments, the teacher gave the students in both groups written instructions of how the experiments should be performed, so that the students could familiarize with the experiments selected for realization. In the class before performing each experiment the teacher checked whether the students understood the instructions and whether they understood every step in the experiment. Particular emphasis was put on what the students should observe in the experiment. After performing the experiments the students in both groups together, with the help of the teacher, during a discussion suggested some conclusions that were written on the board. (Wellington and Grenireson, 2012). At the end of the class, the students recorded in their notebooks the conducted experiments and the conclusions obtained from the results. In doing so, they followed the rules of recording experiments in notebooks. In the E group student experiments were performed. The students formed 18 groups (17 groups consisted of 4 students and one group consisted of three students). Each group had a group leader, who coordinated the work of the group and presented to the whole class the results and conclusions obtained after the group had carried out the experiment. All the groups were doing the same experiments. The groups were formed temporarily by the teacher (groups were heterogeneous). The students performed experiments based on written instructions (in the form of instructional sheets), where they could also find questions that they were supposed to answer after the experiment. In the D group demonstration experiments were performed in three groups of students. The teacher did the experiments in each group of students. When the students were not sure about their answers, the teacher did the same experiment again.

Results and discussion

In lower grades of primary school students learn about matter through learning about the characteristics of individual material and water. On this knowledge students need to build new knowledge of the physical-chemical properties of matter. We analyzed their knowledge about individual material and water with an initial test. When comparing the total score on the initial test for the students of each group separately, it could be seen that the students in the D group got 30 scores more (1568 scores) than the students in the E group (1538 scores). The statistical data shows that this difference is insignificant (Table 2).The results of the initial test indicate that there is no significant difference in the knowledge of both groups of students at different cognitive levels. In both groups, the students obtained similar results at the level of knowledge ($t=1.113$, $p=.078$), comprehension ($t=.811$, $p= .527$), application ($t= 1.126$, $p=.212$), analysis ($t= .974$, $p=.478$), synthesis ($t= 1.742$, $p=.068$) and evaluation ($t=1.033$, $p=.146$). The students in both groups were less successful in the tasks at the level of analysis, synthesis and evaluation. The reason for poor student achievement could be explained by the manner in which they had already learned about the content of materials and water. Based on the interviews with the teachers working in the grades in which the survey was conducted, we concluded that the students performed fewer independent experiments. They were mostly individually performed experiments with water, while the experiments with materials were performed by the teachers. Comparing the values of arithmetic means (AS) and standard deviations (SD) for cognitive levels of the students in groups D and E, it is evident that there is no significant difference indicating the equality of prior knowledge about materials and water of both groups of students.

Table 2. Difference in knowledge of students in D group and students in E group in initial test

Cognitive level	Group	N	Scores at level	$\bar{x}$	SD	t relation	p
Knowledge	E	71	244	3.566	1.2033	1.113	.078
	D	71	246	3.561	1.2194		
Comprehension	E	71	297	4.283	.5206	.811	.627
	D	71	303	4.477	.4975		
Application	E	71	388	5.678	1.3255	1.126	.212
	D	71	390	5.695	1.4871		
Analysis	E	71	550	7.955	3.0526	.974	.478
	D	71	555	8.022	3.1022		
Synthesis	E	71	38	0.733	1.783	1.742	.068
	D	71	46	0.862	1.4736		
Evaluation	E	71	21	0.503	2.0522	1.033	.146
	D	71	28	0.624	1.9603		

After realization of content about the physical-chemical properties of matter with the use of demonstration or student experiments, student knowledge was tested (Table 3). The difference in the total score on the final test was 819 scores in favour of the E group. There was no significant difference in the number of scores that the students in both groups obtained at the level of knowledge, understanding and application. It is significant at the level of analysis, synthesis and evaluation. Similarities and differences in the students' knowledge at various levels are shown in the value of the t test and p value. The students in both groups were equally successful at the level of knowledge ($t= 2.325$, $p=.082$), understanding ($t= .995$, $p=.134$) and application($t= 1.715$, $p=.721$). However, the students in the E group obtained better results than the students in the D group at the level of analysis ($t = 1.929$, $p = .015$), synthesis ($t = 8.652$, $p =.011$) and evaluation ($t = 9.275$, $p = .008$).

Table 3. Differences in student knowledge in D and E groups in final test

Cognitive level	Group	N	Scores at level	$\bar{x}$	SD	t relation	p
Knowledge	E	71	246	3.815	1.93	2.325	.082
	D	71	242	3.822	2.08		

Cognitive level	Group	N	Scores at level	$\bar{\chi}$	SD	t relation	p
Comprehension	E	71	312	4.59	2.12	.935	.134
	D	71	309	4.65	2.41		
Application	E	71	412	6.102	1.3027	1.715	.721
	D	71	404	5.991	1.4158		
Analysis	E	71	705	10.232	2.071	1.929	.015
	D	71	410	6.097	8.315		
Synthesis	E	71	418	6.255	2.023	8.652	.011
	D	71	112	1.887	8.340		
Evaluation	E	71	322	4.846	1.237	9.272	.008
	D	71	119	1.829	8.719		

In order to test their long-term knowledge, the students in both groups were tested again one month later. Similar results were obtained in the students' knowledge at the final test. (Table 4). Difference in scores between the E i D groups at the level of analysis, synthesis and evaluation influenced the total score difference on the retest, and it was 683 scores. The students in the E group showed better results than the students in the D group at the same cognitive levels as they had on the final test (Table 4). A significant difference in the student long-term knowledge at the level of analysis ($t=3.122$, $p=.025$), synthesis ($t= 7.032$, $p =.008$) and evaluation ($t = 8.005$, $p = .003$) is confirmed by the value of t-test and p value. The students in both groups were equally successful at the level of knowledge ($t= 2.301$, $p=.084$), understanding ($t= 1.281$, $p=.227$) and application ($t= 2.571$, $p=.073$). In the retest, the students in both groups obtained worse results compared to the results of the final test. In the final test and retest, the percentage of the students who successfully solved the tasks decreased with an increase in the cognitive levels. This is indicated by the number of scores at each cognitive level. The reason was that they did not revise the content about matter between the final test and retest (Sternberg, 2001). After the content of the physical-chemical properties of matter, the students learned the content of movement. This, among other things, made them forget the content about the physical-chemical properties of matter. The retest results indicate that the process of forgetting was slower in the students of the E group than in the D group.

Table 4. Differences in student knowledge of D and E groups in retest

Cognitive level	Group	N	Scores at level	$\bar{\chi}$	SD	t relation	p
Knowledge	E	71	250	3.896	2.071	2.301	.084
	D	71	246	3.815	2.103		
Comprehen-sion	E	71	309	4.721	2.089	1.281	.227
	D	71	300	4.683	2.128		
Application	E	71	364	5.364	1.864	2.571	.073
	D	71	358	5.253	1.829		
Analysis	E	71	480	7.068	2.112	3.122	.025
	D	71	155	2.381	8.327		
Synthesis	E	71	298	4.296	1.944	7.032	.008
	D	71	108	1.725	9.613		
Evaluation	E	71	147	2.277	1.763	8.005	.003
	D	71	38	0.872	8.058		

The values of the coefficient of variation in the final test (F) and retest (R) for the level of analysis (F:D-17. 74%, E-5. 32%; R: D – 18.05%, E-6.25 %), synthesis (F:D – 19.78%, E-6.88 %; R: D-15.78%, E – 4.82 %) and evaluation (F:D-18.53%, E – 5.21%; R: D – 18.45%, E – 5.03) indicate that the E group students had an equal knowledge at these cognitive levels to the students in the D group. The students in the E group were more successful than the students in the D group in the final test and retest in tasks in which they were supposed to categorize and differentiate between: states of matter (solid, liquid and gas); chemical and physical changes of matter; mixture and matter (substance) and different types of mixtures. They were better at the tasks where they were supposed to analyze ways for making heterogeneous and homogeneous mixtures and suggest how thte components of the mixture can be separated. Also, they showed a better knowledge in the tasks in which they were supposed to propose how to reduce or increase the effect of dissolving some materials (in water and other liquids) and in the task in which they had to evaluate information about liquids (density, evaporation rate, ability to dissolve materials, etc.) and solids (magnetic and electric properties, etc.) based on some criteria. The students in the E group gave better explanations than the students in the D group to the question why certain liquids and solids are used and others are not in the household. They obtained better results than the students in the D group because they have the ability to independently acquire certain knowledge. These results are similar to the findings of other studies (McKee, Williamson and Ruebush, 2007; Logar and Ferk-Savec, 2011) about the impact of demonstration and student experiments on student knowledge. The students in the E group acquired knowledge through the individually performed experiments in small groups, without the teacher's help. In order to find the answers to questions, they had to pay attention during experiments to conduct them properly. They had to properly collect and analyze all the results of the experiments and draw conclusions on their own in small groups. All this required their maximum involvement at all the stages of learning. Group D lacked all this. They were less involved than the E group, because the teacher performed the experiments in front of them. They learned by watching the experiments. Thus, they remembered fewer results and conclusions of some experiments, compared to the students in group E. The students in the D group remembered less in this way and, as a consequence, they acquired less knowledge that they needed for solving tasks at the level of analysis, synthesis and evaluation. They had fewer opportunities than the E group to implement activities (good presentation of their ideas, solutions, ability of giving good arguments for their point of view, discussion, making decisions, taking initiative, etc.) that could help them to acquire a better knowledge about matter (Wellington, 2012).

Conclusion

Student experiments contribute more than demonstration experiments to student knowledge about the physical-chemical properties of matter. Students acquire a better knowledge at the levels of analysis synthesis and evaluation when they do experiments themselves. Demonstration and student experiments have some contribution to improving the quality of students' knowledge about the physical-chemical properties of matter at the cognitive level of knowledge, understanding and application. Student experiments contribute more than demonstration when students need to formulate and build a new knowledge about the physical-chemical properties of matter on the basis of prior knowledge. Student experiments contribute more than demonstration to cooperative learning among students. Therefore, students with poor success acquired a better knowledge of the physical-chemical properties of matter. That is an important objective in the initial chemistry education that should be achieved. Student experiments contribute to a better understanding of different states of matter, differences between pure substances and mixtures, as well as differences between fluids. They contribute more than demonstration experiments for students to understand the relationship between the characteristics of individual materials and their use in everyday life. Students will better understand the impact of various factors on the behavior of substances. Through student experiments more than through demonstration experiments the objectives of the initial chemical education in the structure of matter are achieved. Through student experiments primary school students acquire basic knowledge about the properties of substances more easily. This knowledge could be used later in chemistry, especially when they learn about chemical compounds and chemical reactions. Based on these results, it could be concluded that teachers should use more student experiments to cover the content of the chemical and physical properties of matter.

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