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REVIVAL OF DEMONSTRATION EXPERIMENTS IN SCIENCE EDUCATION

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ABSTRACT: Experiments play an essential role in science research and also in science education. The first experiments were part of science teaching/learning at universities already at the beginning of the nineteenth century. The effectiveness of science education through students engaging in practical activities was preferred by some but doubted by others. The contemporary constructivist approach in science education promotes students' experimentation because students have a greater share in activity and inquiry. Not only are student experiments important for teaching/learning science, but also demonstration experiments play an important role as well. The goal of our design-based research is to answer the question: Does the demonstration experiment have a place in today's constructivist science teaching/learning? What innovations are appropriate for the implementation of demonstration experiments in today's constructivist science teaching/learning? As a result of our design-based research we found several principles for the effective implementation of demonstration experiments in teaching/learning science: an emphasis on the objective of demonstration experiments, controlled observation of demonstration experiments, and development of students' thinking and creativity in demonstration experiments. The appropriate implementation of these demonstration experiments in science education can lead to a better understanding of the nature of experiments, as well as to a better understanding of science concepts, phenomena, science processes and science laws and to increasing the required educational objectives. The next student gain is acquaintance with the experimental skills needed for their own meaningful experimentation under the guidance of a teacher. These skills include the ability to observe consistently and accurately, to use the apparatus correctly, to measure, to create and to test hypotheses of observed phenomena, to analyse results of experiments and to draw conclusions.

Keywords. constructivism, demonstration experiment, science education

INTRODUCTION

Experiments have been used as an irreplaceable instrument in science education for more than two hundred years. From the perspective of contemporary constructivist educational theory there has been an increase in the importance of students' experimentation, which is the basis of students' activity as a foundation for the active creation of their knowledge and skills acquisition. Demonstration experiments carried out by teachers are not at the centre of interest now. But these experiments had a significant role in science education in the past and in our opinion they still have this role. It is important to determine the place of demonstration experiments in science instruction nowadays and whether the time of their revival is coming.

The permanent significance of demonstration experiments has been indicated in some studies (Hodson, 1990, 1993; Milner-Bolotin, Kotlicki, & Rieger, 2007; Zimrot & Ashkenazi, 2007) where it has been verified that students remember and understand appropriate demonstration experiments more than "recipe-following" student experiments, in which students follow prescribed procedures and hope to achieve the right answer (known by the teacher in advance). It is necessary to analyse the role of the student and the demonstration experiment in constructivist teaching/learning science. Sokoloff and Thornton (1997) have developed a learning strategy called the Interactive Lecture Demonstration based on students' prediction and observation of demonstrations in a

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peer-based environment. They speak about the active learning environment and implementation of these demonstrations has shown a dramatic improvement in student attitudes and understanding.

Experts and especially teachers sometimes do not consider the role of demonstration experiments to be very important. Even their incentive effect is questioned. Properly implemented demonstration may help overcome misconceptions and can prevent the emergence of misconceptions (Risch, 2014; Roth, McRobbie, Lucas, & Boutonne, 1997; Thornton & Sokoloff, 1990; Sokoloff & Thornton, 1997). We try to identify the advantages and disadvantages of demonstration experiments and to modify their implementation. Based on a study of literature and using design based research we have developed recommendations for the performance of demonstrations and have applied them in science education. The evidence shows that students of all ages learn science better by actively participating in the investigation and the interpretation of science phenomena and that well-designed demonstration experiments allow students to gather, analyse and communicate data and can help students to better understand science (Mazzolini, Daniel, & Edwards, 2012). Therefore, students need to be motivated for demonstration experiments and to be engaged in observation and discussion. In our study we try to explain why now is the right time for a revival of demonstration experiments in science education.

RATIONALE

We have mentioned the reasons why it is necessary to pay attention to demonstration experiments, not only students' ones. The basis of our considerations could be the history of the implementation of demonstration experiments in science education. This historical analysis can yield significant findings about the factors and conditions that have led to a different emphasis on student and demonstration experiments.

History of Demonstration Experiments

The first demonstration and student experiments were part of science education at universities from the beginning of the nineteenth century. For example, the first laboratory chemistry course in the UK was implemented in 1807 by T. Thomson at the University of Edinburgh (Morrel, 1969, 1972). This approach was gradually reflected in education at primary and secondary school levels. It was considered important to allow students to perform experiments in England in the late 19th century. In 1899, school experimentation was established as a basic requirement for teaching science at most schools in England (Gee & Clackson, 1992). At that time, experiments played a crucial role as confirmation of the theory. A similar process of implementation of experiments took place gradually in many countries. The first hundred years of science experimentation was focused on the support of transmissive teaching. Yet it is possible to recognize some approaches emphasizing the importance of student experiments, especially for promoting understanding of science phenomena. The effectiveness of science education through practical students' activities was also doubted. This caused the first discussions about the relationship between student and demonstration experiments and their roles in education. For example in the beginning of the 20th century Armstrong spoke in favour of students' experimentation, which he preferred to demonstration experiments carried out by teachers (Hodson, 1990).

This debate, however, was affected by factors of efficiency and economics of school experimentation. Student experiments were expensive and time consuming. A significant disadvantage of student experiment was the cognitive inefficiency that arose when an experiment was performed exactly following the guidelines without thinking and without the cognitive activity of the students. These student experiments did not bring about the expected results (Hodson, 1990, 1993) in the understanding of teaching contents. Therefore, in the 1930s in Britain, and similarly in the world, more attention was paid to demonstration experiments (Hodson, 1993).

The discussion about the importance of student and demonstration experiments has continued. Recently, a number of studies have dealt with the effectiveness of practical students' activities in relation to achieving educational objectives (Hofstein & Mamlok-Naam, 2007). The significance of demonstration experiments, their effectiveness and proper implementation in instruction have been discussed by a number of authors (Bowen & Phelps 1997; Johnstone & Al-Shuaili, 2001; Bodner, 2001; Zimrot & Ashkenazi, 2007). There are no evident research results demonstrating a clear relationship between students' experience of experimentation (especially in laboratories) and their learning (Blosser, 1980; Bryce, & Robertson, 1985; Hodson, 1993; Hofstein & Lunetta, 1982, 2004; Lazarowitz & Tamir, 1994).

In the second half of the last century there has been shift towards student experiments in connection with the implementation of constructivist theory into science education. This situation still remains. Students' experimentation has a crucial role in the currently preferred educational strategy IBSE (Inquiry-based Science Education). The widely held constructivist view of learning advocates student engagement via interactivity. However, some studies point to a lack of student engagement in some students' experimentation. Some authors (Hodson, 1993) ask the question what students' activity is developed if they work according to precise instructions and passively fill in the obtained data in prepared charts or relationships in worksheets. Such activity

does not contribute to active knowledge and understanding of phenomena, because the majority of students do not know what they are doing and why. Research findings document (Shrama et al, 2010; Wieman, Perkins, & Gilbert, 2010) that after only passively doing an experiment students come away with an incorrect interpretation of the verified phenomenon! Contrary to common belief, demonstration can be based on a constructivist view of learning. For example the above mentioned specific strategy for physics education, the Interactive Lecture Demonstration (Laws, Sokoloff, & Thornton, 1999; Thornton & Sokoloff, 1990; Sokoloff & Thornton, 1997), has been developed to enhance conceptual understanding. According to Shrama et al. (2010), the Interactive Lecture Demonstration is designed for large lecture classes and, if measured using specific conceptual surveys, is purported to provide learning gains of up to 80%.

We can conclude that all efforts of educators were (and we think always will be) aimed at improving students gains. There is agreement among experts that the way to do this is through the engagement of students. Well-designed demonstration experiments can engage more than "recipe-following" laboratory exercises.

Advantages and Disadvantages of Demonstration Experiments

Based on our analysis we have determined the advantages and disadvantages of demonstration experiments. Among the major advantages are that it is highly important for students to acquire the essential skills for experimentation under the guidance of teachers. These skills are needed for their own meaningful experimentation. These student competences include the ability to observe consistently and accurately, to use the apparatus correctly, to measure, build and test hypotheses of observed phenomena, to analyse the results of experiments and to draw conclusions.

Demonstration experiments are performed by teachers individually or in cooperation with one or more students, in front of the whole class. The advantage is that all students have the opportunity to observe the experiment in progress intently and at the same time. Therefore, it is usually less expensive and time-consuming than student experiments. The teacher can significantly affect students' attention focused on a particular part of the experiment, which could be disturbed by a strong, but less significant stimulus if performing student experiments.

Students learn how to identify the causes of natural processes, connections and relationships between them, to ask questions (How? Why? What happens if?) and to search for answers, to explain the observed phenomena, to look for and solve cognitive or practical problems, and to understand the importance of learning regularities of natural processes in order to predict or influence them.

Demonstration experiments have a completely irreplaceable role in the demonstration of dangerous phenomena and materials such as chemicals, fire, boiling water, electricity, etc. Many experiments are difficult to implement (Brownian motion, etc.), they take a long time (plant growth, etc.) or are economically difficult (expensive chemicals, etc.).

The biggest disadvantage of demonstration experiments is the reduced activity of students and limited perception of experiment through more senses. During the performance of student experiments we can speak about the complex interconnection of hands on and minds on activities of students but during demonstration experiments especially hands on activities are reduced. But it is possible using an appropriate procedure to activate minds-on activities. It is possible to reduce or even eliminate the disadvantages of the demonstration experiment,

RESEARCH QUESTIONS AND METHODS

The objective of our design-based research is to answer the questions: Does a demonstration experiment have a place in today's constructivist science teaching/learning? What innovations are appropriate for the implementation of demonstration experiments in today's constructivist science teaching/learning? Our study presents an example of an appropriate method of implementation of demonstration experiments in science education which combined students' and teacher's activities.

We used design-based research (Reeves, 2006) as a development research method which can be described as a cycle: analysis of a practical problem, development of solutions, evaluation and testing of solutions in practice, and reflection and production of new design principles.

In our case these steps have the following form:

(1) Analysis of practical problems: we identified the existing problems in the implementation of demonstration experiments in science education.

- (2) Development of solutions with a theoretical framework: we created a method (model) of the implementation of demonstration experiments with the use of interaction: teacher - students.
- (3) Evaluation and testing of solutions in practice: our co-researchers - science teachers used action research for testing these model of implementation of demonstration experiments in science lessons.
- (4) Documentation and reflection to produce "Design principles": the final stage of our research was the documentation and establishment of the three design principles for the implementation of demonstration experiments in science education.

RESEARCH RESULTS AND DISCUSSION

The result of our design-based research is the conclusion that demonstration experiments play an important role also in constructivist teaching/learning. There is a lot of discussion about different ways of implementing demonstrations and their effectiveness in promoting student understanding of science concepts. Contrary to the common belief that seeing a demonstration experiment makes students understand or at least remember the phenomena C. Wieman, Nobel Laureate in Physics states, based on his experiences of lectures, that passive observation of a demonstration experiment has educational effects similar to experiments not seen at all (Wieman, Perkins, & Gilbert, 2010). The research findings of Crouch, Fagen, Callan, & Mazur (2004) and Di Stefano (1996) are in agreement with this statement, but their research also shows that learning and understanding is enhanced by increasing student engagement. Based on findings that students may fail to learn from demonstrations if they lack opportunities to discuss what they "saw" and what it meant, experts recommend discussion (Roth, McRobbie, Lucas, & Boutonne, 1997; Laws, Sokoloff, & Thornton, 1999). According to research findings (Milner-Bolotin, Kotlicki, & Rieger, 2007; Moll, & Milner-Bolotin, 2009) students remembered not what they saw, but what they expected to see. Therefore, students need to discuss the presented phenomenon, their observations and conclusions. In this case teachers have the possibility to correct their mistakes and conceptual understanding.

Using our design-based research (Reeves, 2006), we have come to a few important principles for the implementation of demonstration experiments in science teaching/learning: emphasis on the objective of demonstration experiments, controlled observation of demonstration experiments and development of students' thinking and creativity in demonstration experiments (Trnova, Trna, & Novak, 2013). On the basis of these established principles we have compiled a model of implementation of the demonstration experiment in science teaching/learning.

Emphasis on the Objective of Demonstration Experiments

Teachers must state a clear educational objective they want to achieve through a demonstration experiment. Regarding initial motivation, a surprising experiment is enough. Educational objectives can be understanding of science concepts, phenomena and laws or developing skills associated with experimentation such as designing experiments, setting up experimental apparatus, analysing and presenting outcomes of the experiment and drawing conclusions etc. According to the selected objective the teacher should define appropriate involvement of students in the performance of demonstration experiments.

A very important educational objective of demonstration experiments is developing skills associated with designing experiments, setting up the experimental apparatus, etc. These skills are very important for students' experimentation. Many problems with low effectiveness of students' experimentation are connected with the low level of these skills. For example in chemistry or physics lessons students very often have problems with setting up the experimental apparatus, which is the "starting point" for the experiment. Consequently, the gains of students' activities are unsatisfactory. Demonstration experiments provide a convenient means for acquisition of the necessary skills. Teachers can ask students for suggestions regarding the apparatus and correct and explain their mistakes.

Controlled Observation of Demonstration Experiments

Observation (cognition) is of great importance for understanding natural objects, phenomena and laws. Observation results are often an important starting point and the foundation of students' knowledge and skills. When performing a demonstration experiment it is very important for the teacher to distinguish between mere perception (i.e. passive perception of stimuli from the environment) and observation (i.e. intentional and active perception of stimuli from the environment directly connected with mental activity) with respect to age and individual characteristics of students. When preparing a demonstration experiment the teacher must consider how to achieve the best students' controlled observation.

The main activities of the teacher in fostering students' observation include:

- (a) Determining the exact target of observation (students must know exactly what, how and why they are

observing an experiment)

(b) Teaching students how and what to observe, what to notice and in what order

(c) Establishing appropriate observation tasks (neither too easy nor too difficult - with respect to age and individual characteristics of students)

(d) Connecting observation with comments, verbal description of the observed object or phenomenon

(e) Encouraging students to be consistent, independent and patient and to develop a set of the necessary communication skills

(f) Summarizing observations and drawing conclusions (the emphasis is put on essential characteristics)

(g) Drawing students' attention (appropriate duration of the experiment, stimulating students' attention with questions, etc.)

(h) Making sure the experiment can be observed by all students in the classroom

Controlled observation and comments on the ongoing experiment allow students to create the right ideas about the presented phenomena and object features. Compared with student experiments the teacher can check more efficiently whether students draw the right conclusions.

Development of Students' Thinking and Creativity in Demonstration Experiment

The school environment and the teachers are among the most important factors for the development of students' thinking and creativity. To support divergent thinking in students, the teacher should pay attention to students' original, innovative, and unusual ideas and encourage them to become creative individuals. Well-designed demonstration experiments can help to create an appropriate environment and atmosphere for problem solving and other creative activities and they tend to change the role of students from being only spectators to being participants. During well-designed demonstration experiments the following creativity components (Amabile, 1996) can be developed:

- Resourcefulness: students create a wide flow of ideas about the presented concept, phenomenon or law.
- Readiness, perceptiveness: students modify ideas or jump from one idea to another in the context of the demonstration experiment.
- Originality (unusualness of ideas): students create original ideas for solving problems in the context of the demonstration experiment and verify them in practice.
- Imagination: students produce ideas that are not obvious at first sight.
- Endeavour: creativity is not only inspirational, but also hard work; if current ideas are not enough, students come up with new ideas or approaches.

Based on our findings of design based research, it is good practice to divide students into groups. Each student can participate in designing the experimental apparatus, in the procedure for the performance of the demonstration experiment and in searching for answers, explaining the observed phenomena, looking for and solving cognitive or practical problems. Each group presents the results of its work to the other classmates. The teacher can support students' discussion, can correct misconceptions and verify conceptual understanding (Risch, 2014).

Model of Implementation of Demonstration Experiments

Based on the above mentioned principles and analysis of literary sources we developed a model of implementation for demonstration experiments (Trnova, Trna, & Novak, 2013). We recommend using the following procedure for each demonstration:

(1) Before the demonstration the teacher asks students to record individual predictions.

The best activity for the development of thinking and creativity is predicting the progress and outcomes of the experiment. Students create and record their own opinions of how the experiment should develop and why.

(2) Teacher prompts students to discuss with classmates.

The students consult their opinions with their peers in the group. This leads to required confrontation of students' concepts. The teacher can specify students' ideas during the presentation of individual groups, point out any misconceptions and correct them. He/she can also add missing information.

(3) The teacher (maybe in cooperation with one or more students) carries out the demonstration.

When performing experiments students confront their ideas with the real progress of the experiment. As mentioned above, the teacher teaches students to observe, and points out important phenomena, process, changes, etc.

(4) The teacher asks students to discuss the results in the context of the demonstration.

After the demonstration, the students first discuss the results in groups. They compare their predictions with reality. After that, each group presents their findings. The degree of the teacher's involvement is given by the level of students' knowledge and skills. The teacher can monitor whether the students know what has happened in the experiment and why, and check the level of educational outcomes. At a low level of knowledge the

students can just be involved in anticipating the progress of the experiment and there can be an explanation after the implementation by the teacher himself/herself. It is always advisable to let students express their opinion so that the teacher knows whether they understood the presented phenomenon correctly.

(5) *The teacher encourages discussion about analogous situations that are based on the same concept.*

For the teacher, this step may be an indicator of the extent to which students understand the demonstrated phenomenon. It is also very important for the development of thinking and creativity in students.

Such students' involvement in demonstrations corresponds to constructivist teaching/learning fully and minimizes the differences between student and demonstration experiments. According to research (Hofstein & Mamlok-Naanam, 2007; Laws, Sokoloff, & Thornton, 1999), students are motivated by such activities more than by laboratory work, which often limit activity. According to experts (Milner-Bolotin, Kotlicki, & Rieger, 2007; Laws, Sokoloff, & Thornton, 1999; Crouch, Fagen, Callan, & Mazur, 2004; Di Stefano, 1996; Roth, McRobbie, Lucas, & Boutonne, 1997) the gain of a demonstration experiment like this is understanding of concepts and phenomena.

Example of a Model Demonstration Experiment

We present an example of a model of demonstration experiment preparation and collection of carbon dioxide CO_2 in different liquids when students verify its properties. We describe our procedure during the demonstration based on the above mentioned model recommendations:

The teacher, in collaboration with the students, sets up 3 gas collection apparatuses using a descriptive image of the apparatus (Figure 1) as a guideline. As mentioned above it is necessary to revise knowledge about setting up chemical apparatus, to explain and show the procedure.

Instructions for implementation of the demonstration experiment:

Pour 20 cm^3 of 10% hydrochloric acid HCl solution into the separation funnel and put 3 g of calcium carbonate CaCO_3 into the distilling flask. Shut the graduated cylinder filled to the brim with a selected liquid (water or lime water or saturated solution of NaCl) with a stopper, dip under the same liquid in the glass tub and then open it again. Slowly drop by drop add HCl from the separation funnel, which immediately reacts with CaCO_3 to give a colourless gas CO_2 that collects in the graduated cylinder. Observe and compare reactions in each apparatus and explain (see Figure 1).

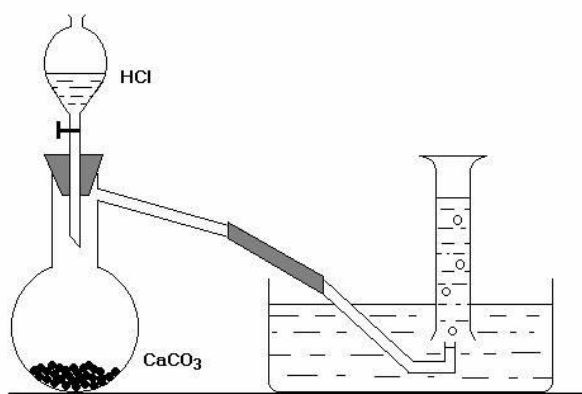


Figure 1. Preparation and Collection of CO_2

(1) *Before carrying out the experiment the teacher asks students to record individual predictions of chemical reactions. Students predict the reactions in individual apparatuses and justify their suggestions based on the properties of CO_2 , which is soluble in water and is acidic oxide. Therefore, the reactions occurring in the individual apparatuses, where CO_2 is collected in different liquids, are different. They predict chemical changes during individual chemical reactions.*

(2) *Students discuss the chemical reactions in individual chemical apparatuses.*

The teacher prompts students to discuss their individual predictions of chemical reactions with their nearest classmates. Students discuss their predictions of how the chemical reactions will perform, they justify their statements and write down the estimated chemical process using chemical equations. If necessary the teacher is in the role of counsellor.

They come up with a chemical reaction that can be used for the preparation of CO_2 and they write it down in the form of chemical equations.

The following chemical reaction was suggested for the presented demonstration experiment:



(3) The teacher (maybe in cooperation with one or more students) carries out the demonstration. The students observe the chemical process. According to the level of student knowledge the teacher comments on the ongoing experiment.

The teacher's comments during the experiment:

- If water has been used, CO_2 dissolves in water partially, but the remaining CO_2 extrudes water from the cylinder and accumulates in it. The volume of the liquid in the cylinder is reduced.
- If lime water has been used, it reacts with CO_2 to form a milky colour caused by insoluble CaCO_3 . The carbon dioxide reacts with $\text{Ca}(\text{OH})_2$ in the cylinder and the glass tub and extrudes it. The volume of the liquid in the cylinder remains unchanged (or changes very little). Mixing pure carbon dioxide with lime water makes the lime water milky white at times. This chemical reaction (sometimes called the lime water test) is used to detect the presence of CO_2 .
- In the case of a saturated solution of NaCl all the liquid is extruded from the cylinder because CO_2 does not react with NaCl solution and it is not soluble in it. If students can calculate the amount of CO_2 produced, they can verify whether the volume produced during the reaction corresponds to reality and compare it with the alternative when CO_2 was collected into water.

(4) The teacher asks a few students to describe the chemical reactions, especially changes in individual graduated cylinders. Students can compare their own observation with their classmates, which is important for the acquisition of the right knowledge. Then students discuss the real chemical process results in the context of the demonstration. Students compare their predictions with the actual course of the reaction and the correct explanation of the reaction. During this confrontation, the students come to an understanding of the relationship between theoretical knowledge about CO_2 and practical experience. Students can repeat individual reactions as student experiments and they will know what they are doing and why in experimentation. If necessary the teacher can explain to help understanding.

(5) The teacher encourages discussion about analogous situations that are based on the same concept. For example students suggest how to prepare CO_2 using substances that are common at home. One possibility is the reaction of sodium bicarbonate and vinegar.

The students' gains from this demonstration experiment are knowledge about properties of CO_2 and understanding of its reaction with different chemical substances.

We verify that students who had the opportunity to participate in the preparation of CO_2 did not follow passively what chemical compounds the teacher used and were able to influence the choice actively. The course of reactions was observed with more interest, because students wanted to verify the accuracy of their predictions about the course of the reactions. The teacher presented the demonstration experiment and commented on the course of the reactions, highlighting significant moments (or letting students comment).

CONCLUSIONS

Demonstration experiments are considered classical but also modern ways of science teaching/learning. Their effectiveness is sometimes unfairly questioned in the context of the constructivist learning approach. As our design-based research and experience have proved the demonstration experiment, when suitably implemented and activating students, is a very good way to develop students' knowledge, skills and interests.

Each experiment, if properly planned and implemented, plays a vital role in understanding natural phenomena. It is necessary especially for younger students to integrate experiments into lessons because their thinking is closely connected with material activity and object handling. Students can understand relationships between phenomena better. They gradually acquire knowledge and its arrangement in the system. This method of learning does not create isolated concepts, for which it is very difficult to determine their essential characteristics, making it difficult for students to characterize, understand and classify them in the structure of acquired knowledge and skills. The best way to achieve this is through students' own practical, explorative and experimental experience.

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