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Evaluation of the Effectiveness of Demonstration Experiment

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Abstract—The results of the use of sensors in the demonstration of chemical experiment were described. In spite of some complication of the equipment, the effectiveness of the demonstration experiment was shown to be high while using sensors.

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The use of sensors [1–3] or digital laboratories [4] makes it possible to conduct experiments demonstrating changes in various visually unobservable parameters: temperature of the system, electrical conductivity, gas phase volume, etc. However, before sensors came into existence, these changes could be demonstrated by certain methods. For example, the heat energy effect of a reaction can be identified by observing indirect indicators (liberation of vapor, freezing of water under a reaction beaker [5, 6], etc.), with temperature and pressure changes in the system fixed using an ordinary thermometer or a pressure gauge, respectively [7]. In this connection, two questions arise: (1) does the use of sensors significantly improve the visibility of demonstration compared to existing demonstration methods and (2) how to choose the experiment tailored to demonstration of particular lecture (training session) points?

To answer these questions, the Chair of General Chemistry, Chemistry Department, Moscow State University, launched in 2007 a research into effectiveness of demonstration experiment conducted with the use of sensors. Unfortunately, literature search did not reveal techniques for comparison of demonstration experiments in terms of their effectiveness, suitable for our purposes. This problem was explored most extensively by V.S. Polosin and coworkers in the 1960s–1980s [8, 9]. However, from our viewpoint, the techniques applied in those studies suffer from several drawbacks. The first is incompleteness of the factors considered. For example, Kaigorodova [9] examined the effectiveness of demonstration experiment in relation to how clearly what happened during demonstration was visible to a specially invited group of respondents. Lecturer's explanations, technique of the experiment, and other factors were neglected.

Along with the above-mentioned techniques used for actual experimental evaluation of the effectiveness of demonstration, it is possible to assess the compliance of demonstration experiment with relevant methodological requirements and, on this basis, to substantiate the choice of a specific experiment.

The methodological requirements to be satisfied by experiment were first formulated by V.N. Verkhovskii in 1911 [10]. Modern authors often provide a significant number (15 or more) of different methodological requirements [11, 12], whereby the evaluation of the effectiveness of demonstration experiment is seriously complicated. Also, the assessment of compliance of demonstration experiment with some methodological requirements, e.g., visibility and accessibility, calls for special study.

We developed a technique to compare demonstration experiments in terms of their effectiveness [13–16] with the use of three parameters evaluating the closeness of correspondence between the title of experiment, or equation of the process, and the content of demonstration experiment (parameter A), visual signal observation adequacy, i.e., correspondence of the description to the visual effect observed (parameter B), and awareness of the purpose of demonstration experiment (parameter C). This technique was tested via surveying students immediately after the lecture. Each student was provided with a survey form which contained several "reactions" (equations of reactions or

Table 1. Assessment of the effectiveness of demonstration experiments based on the use of a sensor and on visual observation of signs of a chemical change. Results of students' surveys in 2009 and 2010

A. Geology Department and Geophysics Department

Year of survey	Parameter	Visual observation			
		Decomposition of FeC_2O_4 (determination of the volume of the evolving gas)	Oxidation of dispersed Fe by atmospheric oxygen	$H_2 + O_2$ explosion	Combustion of Mg in air
2009	A	0.75	Not requested	0.90	0.98
	B	0.60		0.80	0.53
2010	A	0.76	0.69	0.98	0.73
	B	0.60	0.33	0.98	0.33

B. Biology Department, Geology Department, and General Geology

Assessment parameter	Biology Department, 2009		Geology Department, 2010	
	Visual observation			
	Decomposition of $(NH4)_2Cr_2O_7$ ("volcano")	Combustion of P in atmospheric oxygen	$H_2 + O_2$ explosion	$NaHCO_3 + H_2C_2O_4$ interaction upon addition of water
A	0.73	0.98	0.55	0.95
B	0.62	0.95	0.55	0.80

titles of experiments) some of which were specifically the reactions demonstrated experimentally during the lecture. The survey form was separated into three sections, each corresponding to one of the above-mentioned parameters; it could be filled out anonymously (by signing a pseudonym). The names of the respondents were disclosed before the end-of-term exams or immediately after them. The students were informed in advance that the survey results were disregarded in assigning the exam points.

The students had to associate each of the equations of the reactions or the titles of experiments, provided in the first section of the questionnaire, with one of the following statements: "the reaction was demonstrated during this lecture," "the reaction was demonstrated during an earlier lecture," "the reaction was demonstrated during neither of lectures." The answer to this question gives an idea of the recognizability of the reaction (parameter A).

The reactions for which the "demonstrated during this lecture" or "demonstrated during an earlier lecture" options were chosen by a student should be further characterized by the appropriate statements from the second and third sections. The second sections contains statements describing the visual effect of the reaction, e.g., "an explosion occurs during the reaction" or "a precipitate is formed during the reaction." Analysis of the responses to this section of the survey form shows how good was the choice of this specific visual effect and to what extent the students' observations correspond to the real visual effect or to the effect meant by the teacher. Thus, the distribution of these responses allows evaluating the adequacy of the description to the effect observed (option B).

The third section of the survey form contains statements describing the purpose of the experiment, e.g., "this reaction illustrates the thermal effect of the process" or "this reaction illustrates the dissociation of a substance in solution." The students' responses characterize their awareness of the purpose of the demonstration (parameter C).

The technique that we proposed allows experiments to be compared in terms of not only their visibility but also understandability to students. Moreover, this

Table 2. Assessment of the effectiveness of demonstration experiments with temperature changes fixed by different methods

A. Geology Department				
Cohort	"Geophysics"	"General Geology"	"General Geology"	"Engineering Geology"
Temperature change fixing method	Temperature sensor	Beaker freezing to a bench	Temperature sensor	Beaker freezing to a bench
A	0.90	0.73	0.81	0.79
B	0.48	0.25	0.42	0.65
B. Biology Department and Soil Science Department				
Department	Biology Department		Soil Science Department	
	2009	2010	2009	2010
Temperature change fixing method	Temperature sensor		Beaker freezing to a bench	
A	0.86	0.87	0.98	0.44
B	0.81	0.61	0.86	0.21

technique makes it possible to systematically identify the emerging erroneous observations. For example, during demonstration of phosphorus combustion in oxygen (Department of Biology, 2009), ca. 25% of students indicated that, in the course of the reaction, a gas released and the volume of the system increased. On this basis, it was presumed that students are not aware of the fact that P_2O_5 is a solid and are unable to differentiate between gas and smoke. In During analogous lecture delivered to students of the next year's cohort, the teacher drew the students' attention to the fact that, in the course of the reaction, smoke is released from the solid.

Thus, the technique developed by us enables identifying the main factors governing the effectiveness of demonstration experiment. It was unambiguously shown that experiment should be characterized by good visibility and understandability, which findings are in line with the existing methodological requirements for demonstration experiment. At the same time, it was established that some methodological requirements are not absolute. For example, application of this technique allowed a conclusion that the effectiveness of experiment is unaffected by the use of a complex setup whose design is clear to students.

Let us consider this conclusion in more detail, with demonstration of stoichiometric ratios in a chemical reaction taken as an example. The experiment is concerned with measuring the amount of CO_2 released during thermal decomposition of iron(II) oxalate.

The demonstration plant consists of a test tube connected to a sensor for volume measurement, a burner (or alcohol lamp) for heating the test tube with the reactant, a hose connecting the test tube to a volume sensor, a volume sensor, a measuring unit, a laptop, a multimedia projector, and a screen for displaying the output. Thus, the system includes a significantly larger number of objects than that used in demonstration of conventional experiments.

Table 1 summarizes the results of the surveys concerning the demonstration experiments conducted with and without the use of the sensors. The survey participants were students of the Geology Department, Moscow State University ("Geophysics" cohort, 2009 and 2010). Recall that the demonstration effectiveness parameter A provides the proportion of students who characterized the experiment as "demonstrated during this lecture," and parameter B, the proportion of students who adequately described what was happening during the experiment. Out of these two parameters, parameter B is more significant from the viewpoint of effectiveness of the experiment.

As seen from Table 1, the value of the parameter B for the experiment conducted with the use of a complex plant (determination of the volume of gas released during decomposition of FeC_2O_4) is no smaller than that for the clearly visible conventional experiments conducted without the use of plants.

These results should not be interpreted as contradicting the requirement of maximum simplicity for the demonstration plant. In particular, they suggest that, for experiments involving the use of traps for evolving gases, it is possible to discuss the need in and design of traps and not to abandon the experiments because of complicated equipment. Also, complication of the demonstration plant due to the use of sensors will not deteriorate the effectiveness of the experiment, provided adequate teacher's explanations.

The "Decomposition of Ammonium Dichromate" and "Explosion of a Hydrogen–Oxygen Mixture" demonstrations were accompanied by a noticeable visual and sound effect, respectively. Such experiments are usually referred to as "spectacular" and are often demonstrated for the purpose of attracting students' attention. However, our study confirmed the fact (already known to teachers) that a spectacular experiment, e.g., that involving an explosion or a flash, is not always effective. The effectiveness of such experiments depends primarily on the degree of their correspondence to lecturer's explanations.

Table 1 summarizes the results of the surveys carried out during lectures delivered at the Biology Department in 2009 and at the Geology Department ("General Geology" cohort) in 2010. It is seen that the effectiveness of the experiment involving an explosion or an active decomposition ("volcano") is much lower, rather than higher, than that of the "Combustion of Phosphorus" or "Reaction of Soda with Oxalic Acid" experiments characterized by less pronounced effects, which were demonstrated during the same lectures.

The effectiveness of demonstration experiments using sensors was compared to that of experiments based on "conventional" methods of observing the internal parameters of the system, and they proved to be nearly identical, provided compliance with the methodological requirements of good visibility and understandability.

Table 2 summarizes the results of the surveys carried out during lectures for different cohorts of the Geology Department, Moscow State University, in 2009, and during lectures delivered at the Biology Department and Soil Science Department in 2009 and 2010. The lectures were accompanied by demonstrateing endothermic processes, in which the lowering of the temperature in the reaction system was fixed by different techniques. It is seen that the effectiveness of the experiments using sensors is no lower than that of the "conventional" experiments.

Thus, the selection criteria for demonstration experiments involving the use of sensors should be identical to those applied in the case of "conventional" demonstration experiments, namely: closeness of correspondence of experiment to lecture material and good visibility and understandability of the experiment to students. The choice between "with sensor" and "without sensor" options of these same experiment depends on teacher's preferences.

To conclude, sensors significantly simplify the conductance of experiments and in some cases actually make possible doing series of experiments, in particular, those involving comparison of the temperature dependences of the parameter measured, or those in which two or more dependences are compared. In our opinion, specifically these factors will be responsible for progressive increase in the proportion of experiments involving the use of sensors.

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