Problems of digital transformation of laboratory practicum during teaching of natural science disciplines

A V Korshunov[1,3] and E M Knyazeva[2]

[1] Department of Building Materials and Materials Science, Moscow State University of Civil Engineering, Moscow, 129337 Russia
[2] Department of Natural Sciences, National Research Tomsk Polytechnic University, Tomsk, 634050 Russia

[3] E-mail: korshunovav@mgsu.ru

Abstract. The problems of increasing the share of digital learning resources in educational practice for the natural science disciplines, in particular chemistry, within the system of higher technical educational institutions have been analyzed. The elements that should include a laboratory practicum, which is delivered with the use of information and communication technologies, are considered. The necessity of combined use of virtual elements of the practicum with the implementation of real experimental laboratory work is reasoned. One of the possible forms of implementation of virtual laboratory work in chemistry is considered, the necessary components in the content, structure and form of interaction between the teacher and students when performing such work are noted. The problems of digital transformation of laboratory practice during teaching of general and inorganic chemistry are discussed.

One of the most important components of the educational process during teaching of natural sciences, and particularly chemistry, in technical universities is a laboratory course, which aims to develop practical skills of students' work with materials and equipment, obtaining and processing of experimental data skills, planning the experiments, analyzing and comparing the obtained results with the literature data.

With the development of computer-based learning technologies, there is more and more discussion about the need to create virtual laboratory works and to transfer, partially or completely, practicums from laboratories to computer classrooms [1-7]. It is obvious that such arguments cannot be fully guided in the preparation of bachelors, masters or specialists in technical fields, since the level of their responsibility when working in production is so great that it determines not only environmental safety, but also the very existence of the surrounding world.

Modernization of the educational process in higher education institutions is associated with an increase in the share of independent work of students. This is due to the introduction of modern forms of education to the learning process using the capabilities of multimedia and computer technologies. At the same time, a feature of natural sciences and technical disciplines (as opposed to disciplines of the humanities cycle) is the possibility of implementing a mandatory practical block of the curriculum in the form of virtual laboratory work. This makes it possible to expand the range of disciplines studied, and increase their accessibility for students, especially for distance learning students [2-6].

The feasibility of the widespread introduction of the virtual laboratory practicums in educational process on the fundamental and technical disciplines, as a rule, justify a reduction of the cost of conducting experimental studies (expensive materials and equipment, staff), the reduction of time of performance of work ("virtual" time is not comparable with the real one), no need safety and so on [1-7].

However, the noted advantages of virtual laboratory works in relation to the technical disciplines meet certain objections both in terms of their content and form of delivering, and the methodological principles of organizing the learning process. Indeed, delivering virtual laboratory works often leads to an inevitable delay in feedback, which reduces the methodological value of this form of experimental work. At the same time, the principle of collectivism in training is also blurred, which negatively affects the formation of the future specialist's ability to work productively in a team. Performing virtual laboratory work imposes increased requirements on the level of motivation of a student, which in practice does not always work and can reduce the role of systematic learning and, as a result, reduce the quality of technical education.

A separate problem when using the information technologies in training is the complexity of organizing this process and monitoring the learning outcomes. It is generally assumed that the reduction of classical classroom classes will lead to a significant release of teachers' workload. At the same time, our experience in creating virtual laboratory works in chemistry has shown that it takes up to 100-150 hours to develop one work (2 academic hours), test it, make adjustments, etc. The duration of checking the results of such work by students studying remotely is also significantly increased by performing work in a free mode without interrupting their main work, or according to an individual program. In addition to teachers who develop the content part of software, intensive use of the information technologies in training will require the involvement of a large number of programming specialists, technical staff, tutors, managers, etc., who must ensure the functioning of such systems and advise both teachers and students.

It should be noted that most publications devoted to the use of computer technologies in training pay attention only to the information component of the knowledge acquisition process and do not address the issue of developing practical skills to work with real objects, equipment, and coordinated work in a research group. Available in the Internet, virtual laboratory complexes in chemistry are usually characterized by significant simplifications and schematics of the representation of substances, processes, and measurements when performing experimental work. On the other hand, excessive complexity of software products (interactive training programs, virtual practicums, hypertexts) leads to the opposite effect: mastering an "unfriendly" interface of programs requires a lot of time and reduces the motivation of a student, distracts attention from the main tasks when performing specific work. In this regard, the execution time of a virtual work may even increase due to the need to study a virtual device and the functioning of a software product itself.

The controversial aspects of transforming the practical part of the curriculum in technical disciplines into a virtual form include increasing the role of standardization and templates, which limits the opportunities for creative growth of students, narrows their horizons to certain limits provided by a software product. Control of the level of formation of practical skills and abilities in the form of test tasks contributes to the template thinking of students, which also reduces the quality of training of technical specialists who are unable to make responsible decisions in non-standard situations in practice.

The approach to the problem of creating virtual laboratory works and their implementation in the educational process should be differentiated and take into account the specifics of a particular discipline. A virtual laboratory practicum on general and inorganic chemistry has been developed by the authors, and implemented to the educational process at Tomsk Polytechnic University [8]. When creating a set of virtual laboratory works, we formulated the following tasks:

- To make the form, content and hardware design of the work as close as possible to the conditions of a real laboratory.

- To modify the theoretical description of the work and the order of its execution to reduce the volume and increase the information content.
- To use methodological techniques and approaches to increase the share of active and creative learning components.
- To provide control over the assimilation of basic knowledge on the topic, the formation of skills and practical work, processing of experimental results.
- To organize effective feedback from the teacher.

The practicum used in our work includes seven laboratory works on general chemistry and six ones on inorganic chemistry. The development of the practicum included several stages: 1) drawing up a description of the theoretical and practical parts of the laboratory work; 2) actual performance of the work by the developers with video recording of the experiment being conducted; 3) obtaining experimental data, their analysis using computer technologies; 4) transforming the information into a virtual form. To make the interactive practicum as close as possible to the real one, we used photos of objects of study (substances, chemical utensils, appliances), and video materials.

The advantages of the virtual laboratory works developed by us include the realism of experimental research and measurements (if possible, we use full-scale virtual installations, rather than their simplified schemes), a high level of scientific knowledge when performing the experiment and processing the results, the implementation of a creative approach when planning the experiment and performing work by students, the possibility of using the works for full-time and distance learning. A sufficiently high level of interactivity of virtual laboratory work in general and inorganic chemistry [8] allows us to maximize the experimental component of the learning process and get closer to the conditions of reality.

Let's consider the features of the content and form of a virtual laboratory work on general chemistry using the example work "The rate of a chemical reaction". This work is based on measuring the optical density of a solution obtained by merging solutions of sodium thiosulfate and sulfuric acid in certain ratios. During the reaction, sulfur particles are formed, the number and growth rate of which is determined by the initial conditions (concentration of solutions, temperature). The rate of the chemical reaction can be determined by the change in the optical density of the reaction mixture over time. The virtual laboratory complex is made using the Flash technology. The program includes the following blocks: theoretical; hardware design of the experimental part and the procedure for performing the work; drawing up a report, conclusions and monitoring the acquired knowledge, skills and abilities. The theoretical block is a summary of the main information on the topic of the work, including text material, graphs, tables, and illustrations. In this section of the work, hypertext features are implemented, allowing you to specify the meaning of basic terms and physical quantities during the work. A similar feature is provided in the experimental part of the work: each piece of equipment has a symbol, when you point to it, a pop-up help appears with a brief description and purpose of this piece of equipment. At the same time, most elements of laboratory equipment are presented in the form of photos of real objects.

In contrast to real laboratory work, virtual work requires a more thorough approach to describing the order of work. A more appropriate form of representation of the progress of work is the algorithm of its implementation. This is primarily due to the fact that in any virtual work there is a certain amount of schematization and simplification in the representation of phenomena and processes, which requires the introduction of clear restrictions, going beyond which will lead to a program failure or an incorrect result.

Approximation to real laboratory work in the proposed practicum [8] is achieved by introducing greater variability in the choice of conditions and procedure for conducting the experiment. In this laboratory work, it is possible to choose the volume of solutions used in the experiment, an arbitrary sequence of mixing them, an arbitrary sequence of installing cuvettes in the cuvette holder of the photocolorimeter, and a number of other techniques.

This form of representation of the experimental part allows not only to simulate the real conditions of the experiment, but also to take into account the possibility of obtaining erroneous results. When developing the practicum, the authors conducted a large series of experiments, the results of which are included in the program. As a result, even erroneous results that a student can get if they deviate from the algorithm for performing virtual laboratory work are possible in reality.

An integral part of experimental work is the processing of measured results. In the developed virtual laboratory complex, all stages of obtaining and processing the experimental data are reproduced with a high degree of detail: measurement of the optical density of the reaction solution over time, construction of a graphical dependence $A=f(t)$, approximation and optimization of measurement results, determination of physical and chemical parameters of the process by graphical and analytical methods. The results of observations and calculations are made in the form of a report, which can be checked by the teacher as a separate file sent by email, or online.

A controversial point in the purpose of a virtual laboratory practicum is the need and feasibility of its use in the real educational process. The use of the practicum in teaching students on distance learning technology has shown that students try to fill out a report immediately without performing an experiment, or use data obtained by someone and at some time. The disadvantage, or even the advantage, of some virtual works is their rather long duration in time, which makes it difficult to use them in the real mode of laboratory work. We believe that the interactive practicum will be useful for students when preparing for real laboratory work, possibly to work out the missed class. However, it is most appropriate to use it for independent project activities, since the developed virtual practicum contains all the necessary elements for this.

Thus, the use of computer technologies and multimedia tools allows to implement various forms of experimental activities, open up broad prospects in the development of original, and sometimes fundamentally new works of a natural science practicum. From the experience of implementing virtual laboratory work in the educational process, it follows that this form should be used in combination with real experimental work in the laboratory. Virtual works on the natural science and technical disciplines can be used for preliminary acquaintance of students when preparing for work in the laboratory, if it is necessary to repeat the work for better assimilation of the material, when working out missed classes.

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