Using the Virtual Chemical Laboratories in Teaching the Solution of Experimental Problems in Chemistry of 9th Grade Students While Studying the Topic "Solutions"

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Abstract: The article discusses the importance of student research activities for the effective formation of the key competencies of a future specialist in the field of chemistry, the importance of the skills of primary school students to solve experimental problems in chemistry and the conditions for the use of virtual chemical laboratories in the process of the formation of these skills. The concept of "experimental chemical problem" was analyzed. The essence of the concept of "virtual chemical laboratories" is considered and their main types, advantages and disadvantages that define the methodically reasonable limits of the use of these software products in the process of teaching chemistry, in particular, to support the educational chemical experiment are described. The main advantages and disadvantages of the virtual chemical laboratories on the modeling of chemical processes necessary for the creation of virtual experimental problems in chemistry are analyzed. The features of the virtual chemical laboratory VLab, the essence of its work and the creation of virtual laboratory work in it are described. It is determined that to support students' research activities, two types of virtual chemical laboratories are used: distance and imitation. The combination of these types of virtual chemical laboratories in the study of the topic "Solutions" provides an opportunity to take advantage of each of them and increase the level of support for learning research activities of students. Examples of developed virtual chemical works and their essence are given. Based on the implementation of virtual chemical laboratories in the educational process of various educational institutions, it is justified the assumption about the effectiveness of using the developed virtual experimental chemical problems to develop students' research activities when studying the topic "Solutions".

1 INTRODUCTION

Electronic learning tools are widely used in the educational process of teachers from different disciplines, but it is in the chemistry lessons of their use that is perhaps the most appropriate. A chemist should not so much accumulate knowledge as discover something new. Electronic learning tools, in particular virtual chemical laboratories, can bring the process of knowledge of chemical laws to a qualitatively new level: to facilitate the involvement of all participants in the educational process in active search and research activities, self-expression; to ensure the formation of critical and associative thinking, imagination; promote the development of the ability to argue, analyze data, justify and argue the conclusions.

One of the important means of developing chemical thinking and checking the strength of learning is the experimental problems in chemistry. However, now this kind of problems is practically not used in the educational process at school, but it is used at high levels olympiads in chemistry. One of the reasons for this phenomenon is the lack of time for the organization of experimental problems, the risk associated with possible harm to the health of students, the insufficient provision of schools with chemical reagents and equipment, and the like. Virtually all of the above problems can be solved with the help of appropriate means and tools of information and communication

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technology (ICT).

That is why the purpose of our work is to determine the capabilities of the virtual chemical laboratories to ensure the possibility of solving experimental problems in chemistry and developing the appropriate set of virtual computer problems.

To achieve this goal it is necessary to solve the following tasks:

- to analyze the concept of "experimental problem in chemistry" and find out the meaning and place of experimental problems in the school chemistry course;
- analyze the opportunity of using virtual chemical laboratories in pre-profile training;
- to find out the advantages and disadvantages of using different types of virtual chemical laboratories in the creation and implementation of virtual chemistry problems;
- apply the results of research in practice in the form of creating a set of virtual experimental chemistry problems for students in grade 9;
- to analyze the results of the virtual chemical laboratories introduction in the process of studying chemistry (topics "Solutions" in 9 grades).

2 THEORETICAL FOUNDATIONS OF USING VIRTUAL CHEMICAL LABORATORIES IN TEACHING THE SOLUTION OF EXPERIMENTAL PROBLEMS IN CHEMISTRY AND DEVELOPMENT OF STUDENTS' LEARNING RESEARCH SKILLS WHILE STUDYING THE TOPIC "SOLUTIONS"

2.1 Experimental Problems as a Means of Teaching Chemistry

Chemistry is an experimental science, and that is why a chemical experiment in student's develops a chemical style of thinking – the ability to understand the essence of chemical processes, their significance and how to manage them. The modern pedagogical process should be aimed at the child's mastering the very techniques, methods, ways of thinking, that is, the student must master the technology of carrying out appropriate mental actions.

From the studies of famous teachers, didactists, psychologists, the formation of learning abilities is a complex process, the essence of which is to create opportunities for performing work related to learning. In particular, the competence-based approach (Modlo et al., 2018) focuses on the acquisition of skills, experience, and practical application of acquired knowledge in chemistry. Therefore, despite the fact that the content of educational material in chemistry is directed to students mastering practical skills in working with substances, provides for observation and experiment, solving computational and experimental problems, establishing causal relationships, the use of algorithms helps students in solving a number of problems, over time, develop into the ability to solve life problems (Savchyn, 2015).

Thanks to the educational chemical experiment, students acquire practical experience in obtaining facts and their preliminary synthesis at the level of empirical concepts, concepts and laws. Under such conditions, the chemical experiment performs the function of the method of educational cognition, thanks to which new connections and relationships are formed in the consciousness of the student, personal knowledge is formed. It is because of the educational chemical experiment that the activity approach to teaching chemistry is effectively implemented. But it is impossible to carry out an experiment without first considering the result and not drawing up an action plan. That is why the experimental problem solving as a kind of simulator are offered to students.

The solution of chemical problems is an important aspect of mastering the knowledge of the basics of chemical science. The inclusion of tasks in the educational process allows the following didactic teaching principles to be implemented: 1) ensuring the independence and activity of students; 2) the achievement of the strength of knowledge and skills; 3) implementation of the connection of learning with life; 4) the implementation of polytechnic chemistry training, vocational guidance (Zarubko, 2015).

The ability to solve problems develops in the process of learning, and this skill can be developed only in one way – to solve problem constantly and systematically.

Algorithmic actions of students in solving chemical problems in most cases is not at all in strict adherence to a specific procedure, guaranteed to lead to the correct result. But the learning algorithm, according to Savchyn (Savchyn, 2015), first of all means a certain variability of actions in search of the optimal way to solve the problem. In many cases, this variation in the course of isolation is inherent in experimental chemical problems.

Among the arsenal of chemistry teaching methods occupies a special place by the solution of experimental problems in the classroom and the execution of home experiments by students. Experimental problems are problems whose solution is accompanied by experiments. Pak (Pak, 2015) considers experimental chemical problems as a type of cognitive problems in chemistry. In contrast to laboratory work, students solve experimental problems on their own without additional instructions from the teacher. All students' work in solving experimental problems is built on an attempt to apply acquired theoretical knowledge and practical skills to solve a specific problem in conditions are close to real. In its content, the experimental problems can be directed to:

- observation and explanation of phenomena;
- preparation of solutions;
- execution of characteristic and qualitative reactions;
- recognition of substances.

You can also give another classification of experimental problems, according to which they are based on the activities of (Brajko and Mushkalo, 1982):

- familiarization with the properties of substances;
- determining the qualitative composition of substances;
- separation of mixtures;
- phased conversion of substances;
- determination of the quantitative composition of substances, mixtures;
- release of substances from the mixture in its pure form;
- quantitative problems on the laws of conservation of mass of substances and the stability of their composition;
- preparation of solutions of a given concentration and determination of the concentration of an unknown solution.

To solve any experimental problem, a certain sequence of actions is characteristic (Grygorovych, 2016):

1) drawing up an experiment plan (action algorithm), within which it is necessary to determine which specific question should be answered and which experiments should be carried out for this purpose;
2) the implementation of the experimental part;
3) the formulation of conclusions about the possibility of using the obtained experimental data to answer the question posed, and reasonable evidence or refutation of the initial assumptions.

Experimental problems in chemistry can be solved by the following methods: analytical-synthetic, hypotheses, and attempts. But mainly experimental problems in chemistry are solved by the analytical-synthetic method.

The use of experimental problems in the educational process allows us to solve a number of important pedagogical problems, in particular, to develop students' creative abilities and the ability to analyze the condition of the problem and select an experimental model, improve the skills of applying the laws of chemistry, and the like (Brajko and Mushkalo, 1982).

The choice of problem solving method depends on the students having theoretical knowledge and practical skills.

Students should be taught to choose a rational way of solving experimental problems. At the same time, students form the ability to analyze problems, make plans for decisions and reports.

In the class of studying new educational material, experimental problems can be used in various aspects: at the beginning of a lesson, to nominate a problem and arouse students' cognitive activity; during the lesson – in the study of the chemical properties of substances or substances; at the end of the lesson - to consolidate new knowledge.

In the lesson of consolidation of knowledge and the formation of practical skills, experimental problems can be used at its different stages in order to teach students to apply their knowledge to solve practical problems, or to study the device and the principle of the device and acquire the ability to use it.

In the lessons of generalization and deepening of knowledge, solutions to experimental problems are organized to specify the content of physical concepts and to establish new methods for measuring physical quantities and establishing new information about the phenomenon studied.

In knowledge control lessons, solving experimental problems will help test students' ability to apply knowledge in familiar and unfamiliar situations, analyze facts and take a critical look at the results of a chemical experiment.

At the lessons of control and accounting of students' knowledge, as well as at the lessons of generalization and deepening of knowledge, a significant part of the lesson and even the entire lesson can be devoted to solving experimental problems. It is advisable to solve complex problems, in particular the combined ones, which require knowledge of various sections of chemistry.

The ability to solve problems is one of the main indicators of the level of students' mastery of knowledge in chemistry. However, students often cannot solve a difficult task, although they discover the knowledge of theoretical material, they know the definition, the basic formulas, the laws, and solve standard problems. The reason is that students are used to solving typical tasks, and problems of an unknown type cause them to be confused (Mukan, 2002). The tasks are useful, as a result of which students get new information or acquire skills, tasks that make you think logically, based on theoretical knowledge, but with a creative approach. These criteria are exactly the experimental problems.

Selecting experimental problems, it is necessary to take into account the age of students, their psychological characteristics and the level of knowledge in chemistry. Experimental problems are highly effective when students have sufficient knowledge of the relevant material. The form of the problem statement should be convenient for solving at each stage of the lesson.

Today there are many manuals and periodicals in which you can find a selection of experimental problems on a particular topic and are ready to solve them. However, the current trend is the introduction of information technology training in the process of formation of the subject competence of students. It can be said with confidence that students' performance of experimental problems using information and communication technology tools will be more interesting for students and more productive (Brajko and Mushkalo, 1982).

2.2 Development of Students' Learning Research Skills While Studying the Topic "Solutions"

The educational institution must prepare a student who thinks creatively, has theoretical and fundamental knowledge, appropriate skills for the independent work and the ability to process and explain the results of their research.

One of the most important competencies that students acquire in the learning process is research competence – it is the formed quality of personality, which is ex-pressed in the mastery of knowledge, skills and methods for the effective research and the ability of independently acquire new knowledge (Mindeyeva, 2010; Nechypurenko et al., 2016; Leshchenko et al., 2021).

The formation of students' research competence takes place in the process of independent creative research activity and is a necessary condition for the professional development and self-improvement of the individual. Learning research activity is practically the only means for the formation and development of research competencies.

Modern specialized education should initiate and develop the individual's ability to carry out research activities, higher education institutions – to consolidate and deep these skills, as well as bring them to the highest level – the ability to conduct independent research.

Thus, research skills should be formed in school, which takes place in the form of the learning research activities. This is done by involving students to the implementation of the educational research, projects, introduction to the educational process the elements of research activities.

Independent acquisition of new knowledge about the environment is the purpose of learning research activities, in contrast to the usual educational activities (explanatory and illustrative).

We are most impressed by the opinion of Nefedova (Nefedova, 2012), who interprets the research activities of students' as "the process of solving a creative problem that does not have the result, based on mastering the features of the environment through the scientific methods, during which the translation of cultural values".

Therefore, the research is characterized by an active cognitive position which is based on the internal search for answers to any question, through comprehension and creative processing of data, action through "trial and error", the activation of critical thinking.

The work on the formation of research skills in chemistry lessons can be divided into four interrelated areas (Zabolotnyi, 2007):

1) inclusion of research elements in the structure of the lesson while studying new material;
2) organization of laboratory and practical work as research, which will provide an opportunity to increase the level of interest of students in obtaining and interpreting the results of these works;
3) formulation of homework in the form of research can diversify this form of work and make it more interesting;
4) planning and conducting extracurricular activities (research group, project work), using problems with active research activities.

The current state of the most schools in Ukraine does not allow students to carry out research activities on a large scale – covering the whole classes, and is implemented, as a rule, only with children in the category of "gifted" and, mainly, in the form of extracurricular activities.

Solutions is the most common objects of students' research in chemistry. Because the solutions surround a person in nature, everyday life, industry and other areas of activity, students get acquainted with them in childhood. In the course "Natural Science" (5th grade) this acquaintance is more substantive and scientific. Solutions be-come the main object of study and research in the 9th grade during the study of the relevant topic in the course of chemistry (Velychko et al., 2017).

The chemistry curriculum in 9th grade (Velychko et al., 2017) provides for solving experimental problems at this topic, as well as the equations of reactions using solutions with a certain mass fraction of solute; using of demonstration experiments, laboratory experiments, practical work, preparation and defense of educational projects.

Most of these forms of work directly or indirectly contribute to the development and improvement of learning research skills of students. However, it should be noted that a number of planned laboratory experiments and practical work will be performed in an abbreviated or demonstration form. If we talk about the development of research skills of students, then there is a need for additional chemical experiments, which aim to reveal the essence of the phenomena studied, to provide students with a creative approach to solving research problems, to consolidate theoretical knowledge through multiple empirical confirmation.

The most important and most complex semantic parts of this topic are the solubility of substances, its dependence on various factors; saturated and unsaturated, concentrated and diluted solutions; thermal phenomena accompanying the dissolution of substances; the concept of crystal hydrates; electrolytic dissociation. Therefore, the learning research activities should be directed to the study of these semantic parts of the topic.

The topic "Solutions" is the central in the study of chemistry, because it is inter-twined with important sections of inorganic and organic chemistry, chemical technology; the processes of dissociation, ion exchange reactions and other types of reactions are also somehow related to this topic.

The prevalence and availability of solutions also makes them as the unique object for students' learning research activities. A significant number of classes at this topic can be organized in the form of educational research, both laboratory and home (applied).

While studying the topic "Solutions", students acquire skills in working with chemicals, chemical equipment (including measuring equipment), the ability to observe, measure, calculate. At the same time, learning research activities provide an opportunity to do this at a better level, while developing the ability to make assumptions, build algorithms for testing them, conduct experiments and formulate conclusions.

The problems of effective organization of the learning research activities of students while studying the topic "Solutions" are:

- insufficient time to conduct a large number of different learning experiments (especially long-term);
- imperfections in the material support of school chemical laboratories (lack of scientific equipment, potentially dangerous substances and precursors, insufficient number of utensils, etc.);
- limitations related to the physical abilities and health of individual students, features of psychical and mental development, cognitive activity, etc.

2.3 Virtual Chemical Laboratories as a Tools of Teaching Chemistry

When studying chemistry at school, one of the most difficult tasks facing the teacher is to familiarize students with real chemical objects and processes. This difficulty is due to the simplicity and lack of equipment in school chemical laboratories, restrictions on the use of certain chemical compounds in them, reduction of time to study certain topics in curricula, and the like.

A solution to these problems is to use information and communication technologies in the educational process, in particular spreadsheets (Semerikov et al., 2018), augmented reality tools (Nechypurenko et al., 2018; Kharchenko et al., 2021; Midak et al., 2021) and virtual chemical laboratories (VCL) (Nechypurenko et al., 2019; Lytvynova and Medvedieva, 2020).

According to Trukhin (Trukhin, 2002), a virtual laboratory "is a hardware-software complex that allows experiments to be carried out without direct contact with a real installation or in the complete absence of it. In the first case, we are dealing with a so-called laboratory setup with remote access, which includes a real laboratory, software and hardware to control the installation and digitization of the data, as well as means of communication. In the second case, all processes are modeled using a computer".

So, under the virtual laboratories understand two types of software and hardware systems (Trukhin, 2002):

- laboratory installation with remote access (remote laboratories);
- software that allows to simulate laboratory experiments – virtual laboratories (in the narrow sense).

Thus, we can distinguish two types of virtual laboratories: remote and simulation.

Remote virtual chemical labs provide remote access to real lab equipment either in real time or by playing relevant videos. The remote virtual laboratory includes:

1) a real laboratory with real equipment and reagents;
2) software and hardware for control of the corresponding equipment and digitization of the received data;
3) tools of communication to connect users with the first two components.

Virtual laboratories, in which the relevant equipment, substances and processes are modeled using a computer or other gadgets, are a set of programs designed to simulate laboratory work in the laboratory (Trukhin, 2002). Simulation virtual chemical laboratories can be represented by a set of immutable models, as well as mathematical interactive models that can adequately reflect the effects of various user actions associated with changes in the conditions of the experiment, in its results. The main advantage of such virtual chemical laboratories is the ability to implement a creative approach to the implementation of virtual experiments by users and the formation of users a more holistic view of the simulated processes and phenomena.

Both types of VCL have common advantages:

- no need to purchase expensive equipment and reagents. Due to inadequate funding, many school chemical laboratories have old equipment installed that can distort the results of experiments and serve as a potential source of danger for students. Also, in addition to equipment, consumables and reagents are required, the cost of which is quite high. It is clear that computer equipment and software are also expensive, but the universality of computer equipment and its wide distribution and availability somewhat compensate for this disadvantage.
- the possibility of modeling processes, progress or observations of which are fundamentally impossible in the laboratory. Modern computer technologies by means of visualization on the monitor screen provide an opportunity to observe processes that cannot be observed in real conditions without the use of additional equipment, for example, due to the small size of the observed particles or difficult to achieve conditions (ultra high or ultra low temperatures, pressure, etc.).
- the possibility of penetrating into the subtleties of processes and observing the details of a phenomenon that occurs on a different time scale, which is important for processes occurring in a fraction of a second or, on the contrary, last for several years.
- no immediate danger to the lives and health of students. Safety is an important advantage of using VCL, especially in cases where the work involves, for example, the use of hazardous chemicals or devices associated with the use of high temperatures, pressures, electric current, etc.
- saving time and resources for transferring the results into electronic format.
- the possibility of using VCL for informal education and distance learning, is to ensure the possibility of performing laboratory work in chemistry for the lack of access to school laboratories, including when working with children with limited physical abilities who miss classes due to illness or under quarantine time.
- the development of skills to find the optimal solution, the ability to transfer the real problem in model conditions and vice versa.

Perhaps the disadvantage of using virtual chemical laboratories is that the model objects created by the computer are completely supplanted by the objects of the child in the real world. But working with sign systems is the basis of analytic-synthetic activity, that is, thinking does not exist outside of abstraction and symbolization. Also, significant shortcomings of the VCL are the limited information that they transmit to various users' senses, and the inability of students to develop skills in working with real laboratory objects.

By the way of visualization, laboratories are distinguished using two- and three-dimensional graphics and animation.

Also, virtual laboratories are divided according to the way they represent knowledge of the subject area. In one case, virtual laboratories are based on individual facts, limited to a set of pre-programmed experiments. They represent a specific set of laboratory studies, compiled in accordance with the curriculum. Experiments in such virtual laboratories can only be viewed. Intervention in their course is impossible (Derkach, 2008).

Otherwise, conducting virtual laboratory experiments is based on a mathematical model of a real chemical process. Such virtual laboratories provide for the possibility of changing the experimental conditions within certain limits and adequately reflecting these changes in its results. Licensed versions of such programs, as a rule, provide an opportunity to create your own laboratory work. Such virtual laboratories contribute to independent knowledge of the world by students and provide an opportunity for the teacher to realize their creative abilities regarding the chemistry learning process.

The development of VCL, based on mathematical modeling of real chemical processes, is more complex and time-consuming, but significantly expands the possibilities of their application (Derkach, 2008).

Examples of such VCL are Yenka Chemistry (Yenka, 2017), Model ChemLab (Model Science, 2019) and Virtual Lab (VLab) (ChemCollective, 2018). The only virtual chemical laboratory that meets these requirements and is freely available is the Virtual Lab, so we decided to implement the development of a set of experimental problems in it.

Any of the VCL is only a model of the real world, and therefore, like any other model, there is a certain limitation, simplicity. Different virtual chemical laboratories have a different level of simplicity compared to real chemical laboratories: different in detail graphic display of objects, lack of transmission of smells and tactile sensations of objects manipulated in a virtual environment (Nechypurenko, 2012).

ChemCollective Virtual Lab software currently covers more than 50 exercises and problems that help in mastering chemical concepts, mainly related to the study of solutions and the processes that take place in them (Chemcollective.org, 2018b).

On the other hand, the use of remote virtual laboratories provides an opportunity to observe high-quality visualization of relevant processes occurring with real objects – it is possible to conduct high-quality chemical experiments and perform practical work or experimental problems of a qualitative nature. However, this type of virtual laboratories, at least those that are publicly available, do not provide the opportunity to interfere in the process and perform quantitative experiments.

Remote virtual laboratories should be used in the same types of lessons as other virtual chemical laboratories: at the stage of learning or consolidating new material, as independent or home research, in classes of relevant electives or groups, and to test students' knowledge (in the form of experimental problems).

Simulation virtual laboratories have the advantage over remote ones in the ability to change the experimental conditions many times and perform all the experimental operations almost instantly (saving time), the advantage of remote virtual laboratories is a more realistic reproduction of all details of the experiment.

Thus, in our opinion, it is possible to qualitatively support the learning research activities of chemistry students in the study of the topic "Solutions" by combining the capabilities of two types of virtual chemical laboratories – remote (for qualitative experiments) and simulation (for quantitative experiments).

In both cases, there is a need to develop their own laboratory works, which will be implemented through virtual chemical laboratories and will be adapted to the content of the curriculum for secondary schools in chemistry (topic "Solutions", grade 9).

3 METHODICAL BASIS FOR THE DEVELOPMENT OF A SET OF EXPERIMENTAL PROBLEMS IN CHEMISTRY FOR STUDENTS IN GRADE 9 IN THE CLOUD-ORIENTED VIRTUAL CHEMICAL LABORATORY VLAB

3.1 Features of the Virtual Chemical Laboratory VLab

The most accessible of the modern VCL, providing the ability of the user to intervene in the course of a virtual experiment, as well as the possibility of developing their own virtual laboratory work is the Virtual Lab (VLab).

The goal of the VLab virtual chemistry lab, which is a ChemCollective product, is to create flexible, interactive learning environments in which students can approach chemistry as practicing scientists.

ChemCollective began with work on the IrYdium Project's Virtual Lab in 2000. The project was to create training exercises designed to provide interactive, interesting materials that link chemical concepts with the real world.

The project leader is Dr. David Yaron, Professor of Chemistry at Mellon College of Science. Most of the original exercises included in this virtual lab were developed by a team at Carnegie Mellon University, including Yaron, experienced software engineers, student programmers, educational consultants, and editors (Chemcollective.org, 2018a).

Virtual chemical laboratory Virtual Lab is free to install, use and distribute. It can be used both online (by running the virtual lab plugin from the Chem-

Collective website using any browser) or locally by downloading the installation files and installing the program on the computer.

Virtual Lab can also be integrated with the Moodle system using a special plugin. This makes it possible to apply the individual tasks of the virtual lab directly to the specific topics of the Moodle course (Nechypurenko and Semerikov, 2017).

In each assignment of the virtual chemical laboratory VLab, access to chemical reagents, which may include general purpose reagents or compounds specific for a given job, as well as chemical glassware (beakers, conical flasks, graduated cylinders, pipettes, volumetric flasks of various volumes, also a 50 ml burette and plastic cup) and equipment (Bunsen burner, weighing hook and scales).

A separate panel of the program window is designed to provide information about a substance or a mixture: name, volume, state of aggregation, amount of substance (mol or g), concentration (mol/l or g/l), spectrometer data, pH meter, and thermometer. Some of these tools can be disabled if this is required by the condition of the problem, which is solved in this virtual laboratory (figure 1).

All actions with dishes and substances in it are performed in drag and drop mode, that is, by simply dragging objects with the left mouse button. The same operations, as well as some specific actions, can be carried out through the menu that appears when you click on an object with the right mouse button(Yaron et al., 2010).

The essence of the program is to download certain problems and solve them experimentally or calculated with the subsequent experimental verification of the result. There are no restrictions on the number of attempts to perform experience on restrictions on the use of certain quantities of reagents and materials.

Using the exercises of the virtual laboratory VLab, according to its developers, provide the ability to:

- help students who have missed class work in the laboratory to do an experiment from their personal computer, without the need to do work under the supervision of a teacher;
- supplement current work and homework on paper with exercises that allow students to use chemical concepts to design and perform their own experiments;
- monitor the correctness of the assignments of students (students use a virtual laboratory to check the results of their own calculations or qualitative forecasting without risk to their own health);
- to supplement the demonstration experiment conducted in the classroom (teachers first carry out a demonstration in the classroom so that students can see the actual chemical processes, and the students then study the chemical system and processes independently, guided by the problems in the virtual laboratory).

Virtual Lab software currently includes more than 50 exercises and problems that are designed to assimilate chemical concepts, mainly related to the study of solutions and processes in them: moths, stoichiometry and limiting reagents (problems for excess), density, dilutions, dissociation constant, acids and bases, thermochemistry, solubility, chemical equilibrium, redox processes (Chemcollective.org, 2018b).

The installation package of Virtual Lab contains thirteen launch files for this program in different languages, among which Ukrainian since 2014 has been. Running the local version of the program, as well as the old online version, required the presence of a Java plug-in. Recently, this plugin has been blocked by most browsers and antivirus programs, it requires separate settings on the system, therefore, in 2017, the HTML5 version of the VLab was launched on the ChemCollective website in 2017, which currently supports only three languages: English, Spanish and Italian.

On the old version of the ChemCollective site (http://collective.chem.cmu.edu), you can download a special problem editor, the Virtual Lab Authoring Tool, which allows you to both modify existing problems and develop your own from scratch for the local version of the program.

In the problem set, included in the standard version of the VLab program, most of the virtual works are oriented to a level higher than the level of the basic school – core, or college and university. The content of a certain number of problems is structured in such a way that all of them are full-fledged study and research problems (Nechypurenko and Semerikov, 2017). Our work was thus aimed at developing problems that can be classified as experimental chemical problems on the “Solutions” topic, were coordinated with the curriculum, and at the same time were available for primary school students in terms of complexity.

3.2 Creation of Laboratory Work in a Virtual Laboratory VLab

In order to create your own laboratory work, you need to understand how this virtual lab works. The virtual laboratory is launched by running the default.xml file (or default_uk.xml for the Ukrainian version), which is located in the assignments directory. This is the default virtual lab file. This file contains individ-

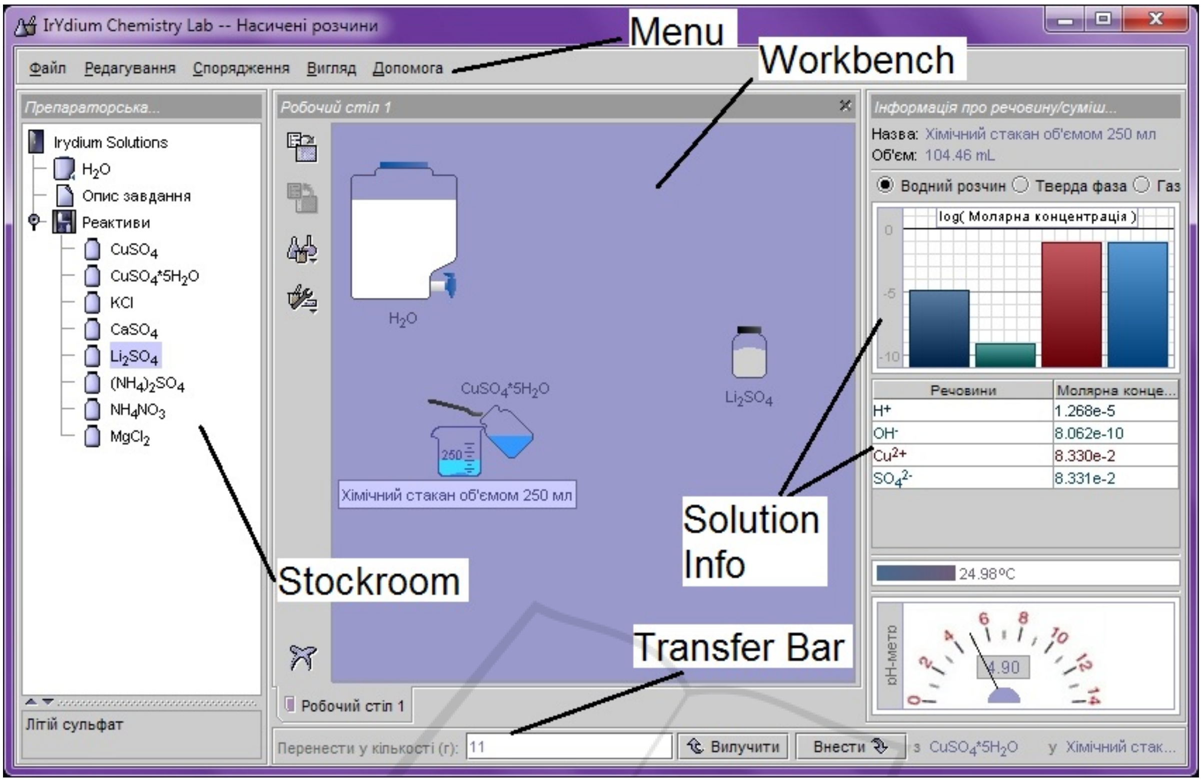

Figure 1: VLab window with virtual laboratory work.

ual properties of the program's working area: the availability of tools (thermometer, pH meter, windows with information about the chemical composition of substances and solutions) and the available modes of substance transfer (accurate transfer, transfer of rounded quantities and realistic transfer). These tools and transfer modes can be either available for work, all or some of them can be turned off depending on the needs of the problem scenario. Also in this file are the ways in which the working area of the program is filled with reagents, possible physicochemical processes with their participation, a description of the work problem, and the like. These default paths lead to files that are in a subdirectory with the same name as the control xml file — that is, the files to work with, are guided by the default_uk.xml file, are in the default_uk directory (the path to it is in the program directory assignments/default_uk). The directory referenced by the control xml file contains typically four files:

- filesystem.xml – contains information about the solutions (reagents) planned for use in this virtual laboratory work and the dishes in which they are contained, their volume or mass, and a brief description of this reagent (name, concentration, etc.);
- reactions.xml – contains information on all possible (planned) chemical reactions with a specific set of substances in this virtual laboratory work;
- species.xml – contains information on all substances available in this virtual laboratory work and their properties (color, state of aggregation, thermodynamic parameters, molar mass, etc.);
- problem_description.html – contains a text description of the problem and instructions for performing virtual lab work.

VLab versions higher than 2.1.0 may also contain the spectra.xml file, which contains the spectral characteristics of the substances that will be displayed in the photocolorimeters window, if it is available for use in this work.

Other laboratory works are started on the same principle, only the control xml-files are located in separate thematic sub-subdirectories in the subdirectories of language localization, for example, the control xml-file of the localized Ukrainian work "Determining the solubility of CuCl2 at different temperatures" CuClSolu.xml is located along the path assignments/problems_uk/solubility.

The list of control xml files with the path to them and a brief description of the work is in the ProblemIndex_uk.xml file (ProblemIndex.xml for the standard English version) in the root directory of the program. From this file that the list of laboratory works available for execution is called up via the menu "File" → "Load problem".

Any of these files can be edited using Notepad (it is important to save changes in the UTF-8 encoding) or any xml file editor. But a more optimal option is to use the special editor Virtual Lab Authoring Tool. There are several options for creating a new laboratory work: from scratch, editing and saving the default xml file, and based on another work. The second way is faster and more rational, since it allows partially (and in some cases, possibly completely) using those reagents, equipment and other necessary parameters of work, since they have already been entered and are guaranteed to work. To make this change, open the control xml file in the Virtual Lab Authoring Tool editor and select "Save As ..." in the "File" menu, specify the new file name and its location. In our case, it was the School catalog, which we created specifically for this set of works. A directory with content files is automatically generated.

Henceforth control xml-file in the editor Virtual Lab Authoring Tool need to edit. The editor window has several tabs, each of which changes a certain part of the work data (figure 2):

- General – contains fields for entering the title of the work, the last name of the author and a brief description of the content of the work.
- Permissions – contains two tabs: Viewers to specify the tools for viewing the properties of substances and their chemical composition will be available during the work; and Transfer Bars to determine the substance transfer parameters available in the job.
- Species – contains tools for creating and editing substances needed in this work. In addition to the formula, the molar mass and the name of the substance, the state of aggregation, as well as its coloring parameters, its standard enthalpy of formation and entropy are obligatory characteristics – these data will be used to simulate chemical reactions between the corresponding substances.
- Reactions – contains tools for planning the flow of physicochemical processes, by defining reactive particles as reagents or reaction products, setting appropriate coefficients.
- Stockroom – provides the ability to create and edit the contents of the "Stockroom" in the virtual laboratory – add cabinets, dishes with reagents, accompanying files (description of the problem, etc.).

At the end of the work in the editor Virtual Lab Authoring Tool you need to save the changes and make the created work in the registry of works so that it becomes available for use. To do this operation, a block is created in the ProblemIndex_uk.xml file (editing with a notepad or xml editor):

```
<DIRECTORY name="The name of the block
   of laboratory works">
  <PROBLEM url="assignments/problems_uk/
 school/File_name.xml">
    <TITLE>Problem title</TITLE>
  <AUTHOR>Autors</AUTHOR>
  <DESCRIPTION>
    A brief description of the problem
  </DESCRIPTION>
 </PROBLEM>
</DIRECTORY>
```

A block limited by <DIRECTORY> ... </DIRECTORY> tags can contain as many individual works as desired, each of which is separated by <PROBLEM> ... </PROBLEM> tags.

Created or edited works become available after the next program launch.

3.3 A Set of Experimental Chemical Problems in a Virtual Chemistry Lab VLab for Use in School When Studying the Topic "Solutions"

The chemistry curriculum in grade 9 (Velychko et al., 2017) provides for the solution of experimental problems on this topic, as well the computational problems using solutions with a certain mass fraction of solute; use of demonstration experiments (thermal phenomena during dissolution: dissolution of ammonium nitrate and concentrated sulfuric acid in water, studies of substances and their aqueous solutions for electrical conductivity, exchange reactions between electrolytes in aqueous solutions) conducting laboratory studies (detection of hydrogen and hydroxide ions in solutions, established approximate pH values of water, alkaline and acidic solutions (sodium hydroxide, hydrochloric acid) using a universal indicator, pH studies search and cosmetic products, the exchange reaction between electrolytes in aqueous solutions, accompanied by precipitation, the exchange reaction between electrolytes in aqueous solutions, accompanied by the evolution of gas, the exchange reaction between electrolytes in aqueous solutions, followed by water absorption, the detection of chloride, sulfate and carbonate ions in solution) carrying out practical work (ion exchange reactions between electrolytes in aqueous solutions) of executing a home experiment

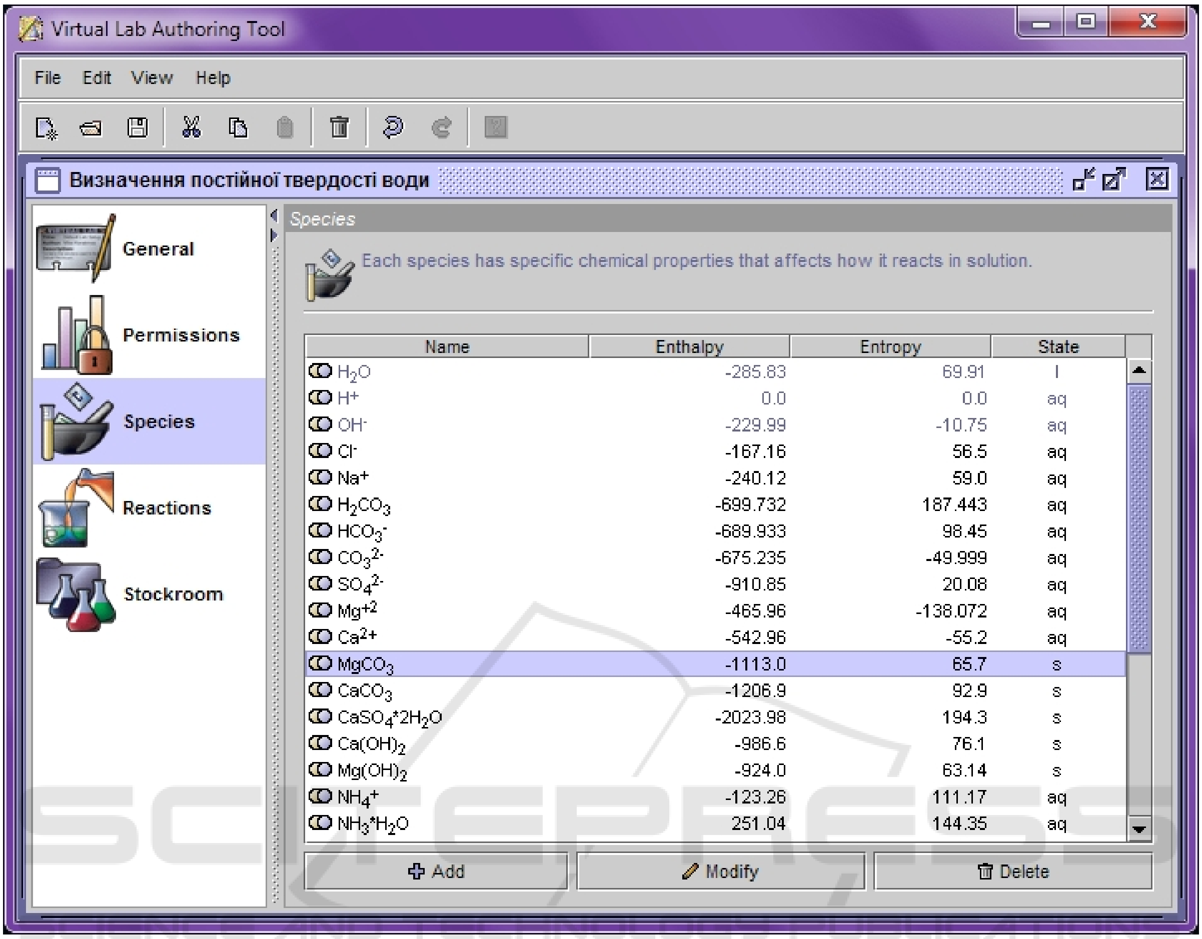

Figure 2: Editor Virtual Lab Authoring Tool window.

(preparing colloidal solutions (jelly etc.)), preparation and protection of educational projects (“Electrolytes in modern accumulators”, “Growing of crystals of salts”, “Production of solutions for provision of medical assistance”, “Research of soil pH of the area”, “Investigation of the influence of acidity and alkalinity of soils on plant development”, “Research pH of atmospheric precipitation and their influence on various materials in the environment”,“Investigation of natural objects as acid-basic indicators”, “Investigation of the pH of the mineral water of Ukraine”).

The most important and most complex parts of this topic are the solubility of substances, its dependence on various factors. Saturated and unsaturated, concentrated and diluted solutions. Thermal phenomena accompanying the dissolution of substances, dissolution as a physical and chemical process, the concept of hydrates, electrolytic dissociation etc. Therefore, experimental problems should be directed to the study of precisely these substantive parts of the topic.

After analyzing the technical and visual capabilities of the Virtual Lab, we determined that it would be most appropriate to create virtual experimental problems related to the dissolution process (its energy and quantitative characteristics), the dissociation process of substances in a solution and determine its pH, as well as the use of some qualitative reactions, indicators and the like. The problems associated with the study of the properties of colloidal solutions, the flow of certain exchange reactions, the extraction of crystals, the study of the analytical effects of qualitative reactions associated with the formation of precipitation cannot be realized either due to the limited possibilities of modeling chemical phenomena in the VLab and due to the limitations of visual accompaniment (for example, to conduct qualitative reactions with the formation of sediment among the equipment in the VLab there are not enough test tubes, and the presence of sediment and its color become noticeable in a glass x on the desktop of the virtual laboratory only in quantities of a few grams or more, does not comply with the principles of qualitative chemical analysis).

Based on all the above, we have created a trial set of experimental problems on the topic “Solutions”, which contains seven problems. The works contain instructions for solving problems and a number of questions that students need to answer.

For example, the laboratory work “Precursor” suggests that the student present himself as a laboratory technician and carry out dilutions of concentrated sulfuric acid, which is on the list of precursors. The task is to prepare equal volumes of solutions with the indicated concentrations.

In the work “Separation of salt mixture”, it is necessary to separate the mixture of crystalline potassium chlorate and sodium chloride by recrystallization of potassium chlorate, based on the difference in the solubility of these salts. The problem contains the order of actions that will help to perform the work. The purpose of this problem is to familiarize students with the methods of purification and separation of substances, the dependence of the dissolution of salts on temperature.

To demonstrate the preparation of saturated solutions, you can use the work “Preparation of saturated solutions of various chemical compounds”. Here the student will be able to prepare solutions by changing the temperature, and on the basis of the data obtained, construct curves for the concentration of a saturated solution of a substance on temperature. The aim of the work is to study the change in the solubility of substances from temperature, the formation of skills in the preparation of saturated solutions, the analysis of the experimental data.

The study of thermal effects of dissolution can be carried out in the work “Thermal effects of dissolution”. In the description, it is reported that during the dissolution of the substance various physical and chemical processes take place with both the solute and the solvent. One of the external indicators that can be easily fixed is the thermal effect observed when various substances are dissolved. The task is to investigate the thermal effects of dissolution of various crystalline compounds in water and to draw appropriate conclusions and assumptions regarding the processes leading to the occurrence of these effects. The purpose of the work is to form an understanding of the thermal phenomena that accompany the process of dissolution and test them in practice, consolidating knowledge about exo- and endothermic processes.

The overwhelmingly developed problems contain a sufficient number of hints so that the student can experiment in a virtual laboratory independently, for example, on a home computer, and some of the problems are quite realistic to reproduce in a real school chemistry laboratory, given the time and possibilities (in this case problem solving in a virtual laboratory can be used as a training option to verify the correctness of theoretical calculations and repeat the order necessary action).

A set of these laboratory works are posted on the website of the Department of chemistry and methods of learning chemistry at the Kryvyi Rih State Pedagogical University (https://kdpu.edu.ua/khimii-ta-metodyky-ii-navchannia/tsikava-khimiia/dlia-vseznaiok/5928-virtualna-khimichna-laboratoriia.html) with the aim of further introducing schools into the educational process and receiving feedback on improving the quality and expansion of this set.

4 CREATION AND TESTING OF A SET OF VIRTUAL LABORATORY WORKS FOR THE ORGANIZATION OF LEARNING RESEARCH ACTIVITIES OF STUDENTS IN CHEMISTRY IN THE STUDY OF THE TOPIC “SOLUTIONS”

Most of the problems in the set developed for the topic “Solutions” in VLab are formulated in a research (problem) style – the student has a task:

1) to obtain a certain practical result;
2) to study processes and phenomena, the exact properties of which are unknown to him in advance.

In the first case, the student has the opportunity to create their own algorithms and check their adequacy in practice, but in a virtual environment. The use of trial and error method is not ruled out. In the second case, completing the problem will mean for the student the discovery of subjectively new patterns, properties, and so on. That is why, the student has the opportunity to independently, based on the results obtained in the virtual chemical laboratory, to draw conclusions about the influence of the certain factors on the dissolution process, and only then compare them with those in textbooks described, heard from the teacher’s story, etc.

Most of the problems contain enough prompts for the student to experiment in a virtual laboratory on their own, for example, at a home computer, and some of the problems can be reproduced in a real educational chemical laboratory of the school if time and opportunity (in this case the problem in the virtual laboratory can be used as a training option to check the correctness of theoretical calculations and repeat the order of necessary actions).

The VLab virtual chemical laboratory provides the possibility of independent repeated experimentation with various substances and their solutions, with the involvement of accurate measuring instruments, but it is not designed to perform qualitative reactions. Most qualitative reactions do not require accurate calculations and measurements, but they do require as clear an analytical effect as possible, not distorted by the imperfection of the object's appearance in its model. For the virtualization of qualitative experiments, qualitative visualization is often more desirable than the ability to make accurate measurements. Since in the topic "Solutions" a certain amount of student research is related to qualitative chemical experiments (performing qualitative reactions, determining the acidity of the environment using indicators, etc.), there is a need to create a resource to support of qualitative chemical experiments. The most realistic transmission of visual information about an object is a video recording. The essence of the developed remote virtual chemical laboratory is to provide users with remote access to a set of substances that can be used to perform high-quality laboratory experiments. At the same time, we tried to anticipate various options for user actions, including those that could have been done accidentally, without logical justification. To do this, the program interface is organized in such a way that the user has two sets of reagents. Any reagent from the first set can be mixed with any reagent from the second. Selecting the appropriate pair of reagents triggers a short video recording of the mixing of these reagents in a real chemical laboratory. The user can not change the number of reagents or the order of their addition, but has the opportunity many times to observe high-quality visualization, accompanied by a textual description of the nature of the reaction that occurs.

The availability of such a virtual chemical laboratory can be ensured by placing it on the Internet on the pages of the site. The window interface of such a remote virtual chemical laboratory is essentially the html-page of the site. For the operation of a laboratory installation with remote access, it is necessary that the site page contains a set of elements of JavaScript, video, codes, etc. that relate to a separate laboratory work (figure 3).

The operation of the remote virtual chemical laboratory created by us is provided by a number of objects located in different directories:

- the *favicons* folder contains favicon elements, ie site icons for different browsers;

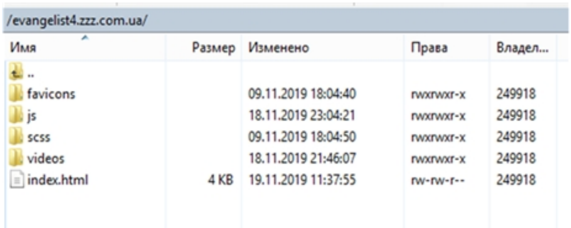

Figure 3: Elements of the site of the laboratory installation with remote access.

- *js* folder is a folder for saving java script files that provide dynamic interactivity on the site;
- *scss* folder contains style files that form the external design and stylization of the site page;
- all videos of the experiments that we recorded for running on the site are saved in the *videos* folder;
- the *index* file is the main one, because the main startup code of the laboratory is written in it.

The following online page of the virtual chemical laboratory involves the execution of certain program code, which can be edited by connecting to an FTP server and launching Notepad++ or xml-editor.

The general principle of the first virtual laboratory with remote access on the topic "Indicators" is to select buttons from the upper left corner – the indicator, and the lower left corner of the solution with a certain level of acidity, such a combination of pressing "show" allows you to run videos where the first reaction, change of color of solution is shown (figures 4 and 5).

To return to the indicator and solution selection, press the "Clear" button in the middle on the left and start the selection again.

The following laboratory work No 2, created on the basis of the site, is based on an experimental problem on "Qualitative reactions to the most common anions". The general principle of operation is similar to the virtual chemical laboratory "Indicators" and consists in selecting the buttons from the upper left corner – solutions of reagents $AgNO_3$, $Pb(NO_3)_2$, $BaCl_2$, and the lower left corner - a solution containing an unknown anion to be determined by students. When you press the "Show" button, a video is launched, which shows the course of the chemical reaction between the selected solutions.

It should be noted that both laboratory works can be used as research: the "Indicators" lab contains not only the indicators described in the textbook, but also non-standard for the school curriculum – bromocresol purple, congo red, red cabbage juice, and therefore work with them is easy to organize as a research. The work "Qualitative reactions of some anions" is generally an experimental problem for the recognition of

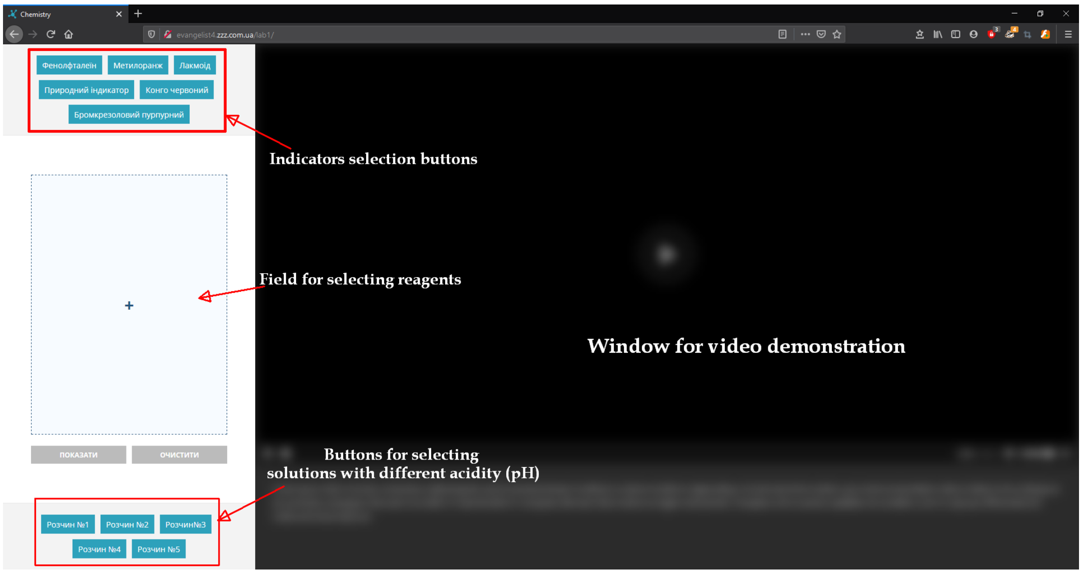

Figure 4: Location of the buttons of the main elements of the remote laboratory.

anions.

Both laboratory works are posted on the website http://distvlab.easyscience.education/, where they are available at the links http://distvlab.easyscience.education/Lab1 and http://distvlab.easyscience.education/Lab2.

5 RESULTS

The created virtual laboratory works were tested during chemistry lessons and optional classes in several educational institutions of the city of Kryvyi Rih during 2019: Kryvyi Rih Central City Lyceum, Kryvyi Rih Central City Gymnasium, schools No 66, No 21 and Kryvyi Rih College of National Aviation University of Ukraine. To do this, teachers used personal computers and netbooks, SMART Board interactive whiteboards, and smartphones and tablets.

Chemistry teachers especially noted the convenience of using virtual chemical laboratories to prepare for laboratory work or their partial replacement, and to organize effective independent work of students.

Students were asked a questionnaire with the following questions:

1. “Were you interested in using virtual chemical laboratories?”
2. “Was it easy for you to use virtual chemical laboratories?”
3. “Will virtual experiments help you better understand the theoretical material of the topic?”
4. “Did virtual chemistry labs help you better prepare for classroom practice work?”
5. “What did you like most about using virtual chemistry labs while studying chemistry?”

144 students took part in the survey. The results of the survey are shown in table 1.

The fifth question with an open answer was often answers by students, which can be formulated as: “non-standard approach to the organization of lessons”, “unusual and novelty of the use of virtual chemical laboratories”, “the possibility to make experiments without time or strict responsibility for the quality of individual actions”, “the possibility to independently make experiments as you want or interesting”, “the possibility to prepare at home, especially if you missed the lesson”. According to the observations of teachers involved in the experiment, the use of virtual chemistry laboratories increased students’ desire to experiment and reduced their fear of making mistakes during the experiment, making erroneous conclusions, and so on. This was evidenced by the high results demonstrated by students in performing practical work and experimental problems within the topic “Solutions”.

Thus, the majority of students noted a positive effect from the use of VCL primarily for practical work preparation, as well (a slightly lower percentage) in the acquisition of theoretical knowledge. For the vast majority of students, VCL was an interesting means of chemistry learning (perhaps due to novelty and non-standard), but a smaller percentage of students noted the ease of use of VCL, due to the same novelty for students, and therefore lack of skills in using

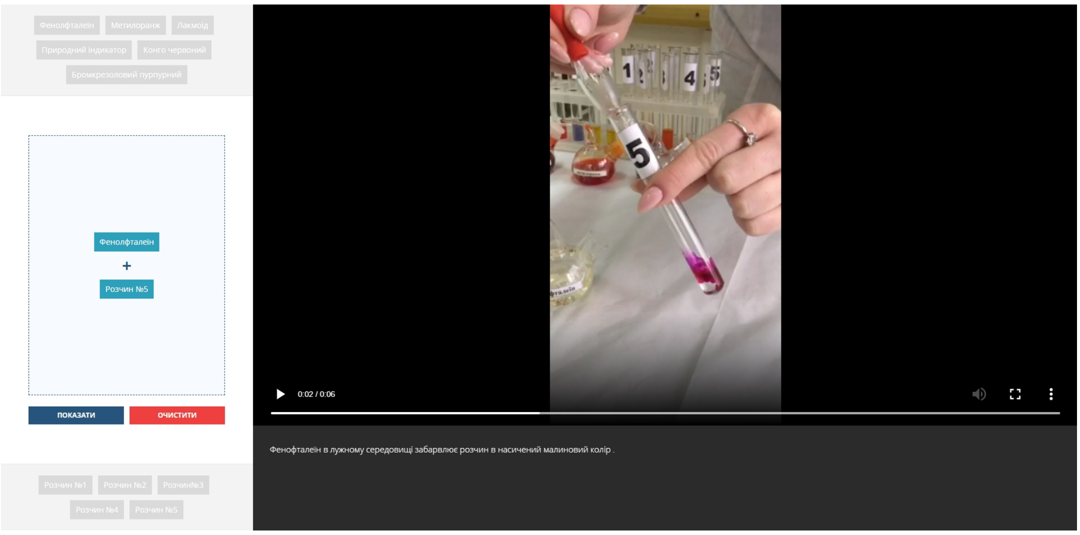

Figure 5: Remote chemical laboratory operation: selected buttons “Phenolphthalein” and “Solution No 5”.

Table 1: The results of student surveys.

Number of question	Answers to questions				
	“No”	“Rather no”	“Hard to say”	“Rather yes”	“Yes”
1	0	11 (7.6%)	52 (36.1%)	81 (56.3%)	
2	0	3 (2.1%)	18 (12.5%)	56 (38.9%)	67 (46.5%)
3	0	6 (4.2%)	14 (9.7%)	45 (31.2%)	79 (54.9%)
4	0	4 (2.8%)	13 (9%)	38 (26.4%)	89 (61.8%)

these teaching tools.

6 CONCLUSIONS

1. The learning research activities are an integral part of a quality educational process, especially in the study of natural sciences. The learning research activity differs from ordinary learning in that it requires an active cognitive position based on the internal search for answers to any question related to the understanding and creative processing of information, action through “trial and error”, and from scientific research it differs, first of all, in the results – the acquisition of subjectively new knowledge, the formation of research skills and other personality traits of students.
2. One of the varieties of learning research activities of students in chemistry is experimental chemical problems – a separate type of chemical problems, the solution of which is necessarily accompanied by the practical implementation of a chemical experiment.
3. Experimental chemical problems are characterized by the methodological feasibility of their use in various types of lessons, at different stages of a lesson and in extracurricular work.
4. One of the most important and integral topics in the school course of chemistry is the topic “Solutions” – while studying this topic, students consolidate knowledge of general and inorganic chemistry, acquire skills to perform experiments, gain theoretical and practical basis for further study of chemistry.
5. Pre-profile chemistry training contains a significant amount of experimental activity of students, and one of the ways to overcome the contradiction between the need to carry out a training chemical experiment and the lack of sufficient time, necessary equipment and reagents, the use of virtual chemical laboratories — special computer programs that make it possible to simulate the physical chemical phenomena or to conduct experiments without direct contact with a real chemicals set or the complete absence thereof.
6. Virtual chemical laboratories are, first of all, unique simulators – tools that allow users to test the algorithm of actions, to trace the logic of certain laboratory operations during the experiment, to practice skills of collecting and recording the necessary data, experimental results and

more. Remote virtual chemical laboratories have the advantage of conducting qualitative experiments, and simulation VCL – quantitative chemical experiments.

7. Virtual chemical laboratories in some cases can be used as a replacement for a real chemical experiment, if for some reason it's implementation is impossible.
8. Virtual chemical laboratories provide an opportunity to safely and economically implement the development of research competencies of students through the use of experimental chemical problems, which can be performed entirely in virtual mode or in simulator mode with subsequent implementation in the form of a naturaly experiment.
9. Virtual chemical laboratories are a rather labile learning tool that can be used at almost any stage of the lesson: at the beginning, at the stage of learning new knowledge, at the stage of consolidation of knowledge and at the stage of testing, as well as for independent and homework. In the case of proper organization of work with them, the student has the opportunity to perform learning research at any time and in any place.
10. The best option for quality support of learning research activities of students in chemistry by solving experimental chemical problems (including distance learning) in the study of topic "Solutions" is a combination of two types of virtual chemical laboratories – remote (for qualitative experiments) and simulation (for quantitative experiments).
11. Currently, a set of virtual laboratory works has been created, consisting of seven problems in the simulation VCL Virtual Lab and two experimental problems in the remote VCL. Currently, a set of virtual laboratory works has been created, consisting of seven problems in the simulation VCL Virtual Lab and two experimental problems in the remote VCL.
12. The created virtual laboratory works were introduced into the educational process of several educational institutions in Kryvyi Rih during 2019 and received mostly positive feedback from both chemistry teachers and students. This makes it possible to say that virtual chemical laboratories have a high potential for organizing and improving the learning research activities of students in chemistry while studying the topic "Solutions" and need further improvement taking into account the results of its implementation in the school educational process.

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