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Enhancing student research activities through virtual chemical laboratories: a case study on the topic of Solutions

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Abstract. This paper explores the significance of student research activities in fostering the key competencies essential for the future specialists in the field of chemistry. Specifically, it emphasizes the importance of primary school students' ability to solve experimental problems in chemistry and highlights the role of virtual chemical laboratories in facilitating the development of these skills. The concept of "experimental chemical problem" is thoroughly analyzed, providing a comprehensive understanding of its essence. Moreover, the paper delves into the concept of "virtual chemical laboratories", discussing their primary types, advantages, and disadvantages, which define the methodical boundaries for their implementation in chemistry education, particularly in supporting educational chemical experiments. Furthermore, the study scrutinizes the major benefits and limitations of virtual chemical laboratories regarding the modeling of chemical processes necessary for creating virtual experimental problems in chemistry. The distinctive features of VLab, a virtual chemical laboratory, are elucidated, shedding light on its operational essence and the process of designing virtual laboratory work within it. Notably, two types of virtual chemical laboratories, namely distance laboratories and imitation laboratories, are identified as integral components for supporting students' research activities. The synergistic combination of these laboratory types, particularly in the study of the topic "Solutions", offers an opportunity to harness the advantages of each type and elevate the level of support for students' research activities during the learning process. To exemplify the practical implementation of this approach, the paper presents developed virtual chemical works, providing insights into their essence and purpose. Drawing from the successful integration of virtual chemical laboratories in diverse educational institutions, the paper justifies the assumption regarding the effectiveness of utilizing the developed virtual experimental chemical problems to foster students' research activities within the context of studying the topic "Solutions". This research contributes to the field of educational technology by providing evidence-based insights into the potential of virtual chemical laboratories for enhancing student engagement and competency development in chemistry education[1].

Keywords: virtual chemical laboratories, solutions, learning research activity, student research activities, key competencies, chemistry education, experimental chemical problem, distance laboratories, imitation laboratories, virtual experimental problems

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1. Introduction

Educational technology has revolutionized teaching practices across various disciplines, with chemistry lessons benefiting significantly from the integration of electronic learning tools. Unlike simply accumulating knowledge, the field of chemistry emphasizes the discovery of new phenomena. Virtual chemical laboratories, among other electronic learning tools, offer a transformative opportunity to enhance the understanding of chemical laws. By facilitating active engagement, research activities, and self-expression, these tools promote critical thinking, associative thinking, imagination, data analysis, and the ability to construct well-founded arguments and conclusions.

Experimental problems in chemistry serve as valuable means to develop chemical thinking and assess the depth of learning. Unfortunately, the utilization of such problems is scarce in regular school curricula, reserved mainly for advanced chemistry olympiads. Several factors contribute to this disparity, including time constraints, safety concerns associated with physical experiments, inadequate availability of chemical reagents and equipment in schools, and other logistical challenges. However, the application of information and communication technology (ICT) can address these obstacles effectively.

Therefore, the aim of this study is to explore the potential of virtual chemical laboratories in facilitating the resolution of experimental problems in chemistry and developing a corresponding set of virtual computer-based problems. To accomplish this objective, the following tasks are undertaken:

- Analyzing the concept of "experimental problems in chemistry" and determining their significance and role within the school chemistry curriculum.
- Investigating the feasibility of integrating virtual chemical laboratories in pre-professional training.
- Identifying the advantages and disadvantages of different types of virtual chemical laboratories in creating and implementing virtual chemistry problems.
- Applying research findings by developing a comprehensive set of virtual experimental chemistry problems for 9th-grade students.
- Analyzing the outcomes of integrating virtual chemical laboratories into the teaching and learning process, focusing specifically on the topic of "Solutions" in 9th-grade chemistry.

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, being an experimental science, fosters a chemical style of thinking among students, enabling them to comprehend the essence and significance of chemical processes and acquire the necessary skills to manipulate them. In the modern pedagogical context, it is crucial to guide students in mastering the techniques, methods, and modes of thinking inherent to the discipline, thus facilitating the acquisition of learning abilities.

Extensive research conducted by renowned educators, didacticians, and psychologists emphasizes that the development of learning abilities is a multifaceted process, requiring the creation of opportunities for engaging in meaningful learning tasks. The competence-based approach, which places emphasis on skill acquisition, experiential learning, and the practical application of acquired knowledge in the field of chemistry, aligns well with this perspective. While the curriculum content in chemistry aims to equip students with practical skills in working with substances, promoting observation, experimentation, problem-solving, and the establishment of causal relationships, algorithmic approaches assist students in navigating various problem-solving scenarios and ultimately cultivate their ability to address real-life challenges.

The educational chemical experiment serves as a catalyst for students' acquisition of practical experience in gathering facts and their initial synthesis at the level of empirical concepts, principles, and laws. This process empowers students to actively construct new connections and relationships within their cognitive framework, thereby fostering the development of personal knowledge. Furthermore, the educational chemical experiment effectively embodies the activity-based approach to teaching chemistry. However, conducting experiments necessitates a preliminary consideration of the desired outcome and the formulation of an action plan. Consequently, students are offered the opportunity to engage with experimental problem-solving as a form of simulation.

Solving chemical problems represents a crucial aspect of mastering the fundamentals of chemical science. The inclusion of problem-solving tasks within the educational process enables the implementation of several essential didactic principles: 1) fostering students' independence and activity; 2) ensuring the acquisition of robust knowledge and skills; 3) establishing connections between learning and real-life applications; and 4) promoting polytechnic chemistry education and career guidance.

The ability to solve problems develops progressively throughout the learning journey and can only be honed through continuous and systematic problem-solving practice. However, it is important to note that the algorithmic actions employed by students in solving chemical problems do not rigidly adhere to a specific procedure that guarantees a correct solution. According to Savchyn [17], the learning algorithm primarily entails a certain degree of variability in actions as students explore different pathways to arrive at an optimal problem-solving approach. This variation is often inherent in the context of experimental chemical problems.

Among the various teaching methods employed in the field of chemistry, the solution of experimental problems in the classroom and the execution of home experiments by students hold a prominent position. Experimental problems are characterized by their integration of problem-solving tasks with accompanying experiments. Pak (year) considers experimental chemical problems as a subtype of cognitive problems in chemistry. Unlike laboratory work, students tackle experimental problems independently, without additional instructions from the teacher. The resolution of experimental problems entails the application of acquired theoretical knowledge and practical skills to address specific challenges that closely resemble real-world scenarios. Experimental problems in chemistry encompass a range of objectives, such as:

- Observing and explaining phenomena.
- Preparing solutions.
- Conducting characteristic and qualitative reactions.
- Identifying substances.

Additionally, experimental problems can be classified according to their focus on the following activities [1]:

- Familiarizing students with substance properties.
- Determining the qualitative composition of substances.
- Separating mixtures.
- Phased conversion of substances.
- Determining the quantitative composition of substances and mixtures.
- Isolating substances in their pure form from mixtures.
- Solving quantitative problems related to the laws of conservation of mass and the stability of substance composition.
- Preparing solutions of specified concentrations and determining the concentration of unknown solutions.

Solving experimental problems typically follows a specific sequence of actions, as outlined by Hryhorovych [6]:

1. Formulating an experimental plan (action algorithm) that identifies the specific question to be answered and outlines the necessary experiments to address it.
2. Conducting the experimental procedures.
3. Formulating conclusions based on the potential use of the experimental data to answer the initial question, accompanied by logical reasoning and justification or refutation of initial assumptions.

Various methods can be employed to solve experimental problems in chemistry, including the analytical-synthetic approach, hypothesis testing, and trial-and-error. However, the analytical-synthetic method predominates in the resolution of experimental problems.

The integration of experimental problems into the educational process offers several pedagogical benefits, such as fostering students' creative abilities, enhancing their problem analysis skills, promoting the application of chemical laws, and more [1].

The choice of problem-solving method depends on students' level of theoretical knowledge and practical skills. It is essential to guide students in selecting rational approaches to solving experimental problems and develop their ability to analyze problems, formulate action plans, and present findings.

Experimental problems can be incorporated at various stages of the lesson while introducing new educational material to stimulate students' cognitive activity, during the lesson to explore the chemical properties of substances, and at the end of the lesson to reinforce newly acquired knowledge.

During consolidation lessons, which focus on knowledge consolidation and the development of practical skills, experimental problems can be employed at different stages to train students in applying their knowledge to practical problem-solving or to study the functioning and principles of devices and acquire the associated skills.

During generalization and deepening lessons, the solution of experimental problems helps refine the understanding of physical concepts, establish new measurement methods for physical quantities, and acquire new information about the phenomena being studied.

In lessons focused on knowledge assessment and evaluation, as well as in lessons aimed at generalization and deepening of knowledge, a significant portion or even the entirety of the lesson can be devoted to solving experimental problems. It is advisable to incorporate complex problems, particularly those that require knowledge from various areas of chemistry.

The ability to solve problems serves as a key indicator of students' mastery of knowledge in chemistry. However, students often struggle with challenging tasks, even if they possess a theoretical understanding, know definitions, formulas, and laws, and can solve standard problems. This difficulty arises because students are accustomed to solving typical tasks, and encountering unfamiliar problem types can disorient them. Mukan [9] highlights the value of tasks that facilitate the acquisition of new information or skills, engage logical thinking based on theoretical knowledge, and foster a creative approach. Experimental problems meet these criteria.

When selecting experimental problems, consideration should be given to students' age, psychological characteristics, and level of knowledge in chemistry. Experimental problems are most effective when students possess sufficient knowledge of the relevant material. The problem statement should be presented in a format that is conducive to problem-solving at each stage of the lesson.

While numerous textbooks and periodicals provide collections of experimental problems on specific topics for students to solve, the current trend is to incorporate information technology in the process of developing students' subject competence. Utilizing information and communication technology tools for students to tackle experimental problems not only enhances their interest but also increases productivity [1].

2.2. Enhancing students' learning research skills in the study of "Solutions"

Contemporary educational institutions face the crucial task of equipping students with the ability to think creatively, possess theoretical and fundamental knowledge, and cultivate the skills necessary for independent work, including the proficiency to conduct research and effectively communicate their findings. Among the various competencies developed during the learning process, research competence stands as one of the most significant, encompassing the mastery of knowledge, skills, and methods essential for effective research and independent knowledge acquisition [7, 15].

Research competence formation occurs through independent and creative research activities, serving as a prerequisite for individual professional development and self-improvement. Such activities provide students with the means to develop and hone their research competencies effectively. As such, research skills should be cultivated within schools by involving students in educational research projects and integrating research elements into the learning process [16].

Learning research activities differ from conventional educational methods, as their primary objective is the independent acquisition of new knowledge, rather than mere explanation and illustration [16]. They foster an active cognitive position, stimulating students to explore answers to questions, engage in critical thinking, and employ creative approaches to problem-solving, including trial and error [16]. The study of the topic "Solutions" in chemistry offers a significant opportunity for students to cultivate their research skills, given the ubiquity of solutions in the natural world, daily life, and various industries [19].

The 9th-grade chemistry curriculum extensively addresses the study of solutions, incorporating experimental problem-solving, equation formulation, demonstration experiments, laboratory investigations, practical work, and the preparation and defense of educational projects [19]. While these activities contribute directly or indirectly to the development of students' learning research skills, it is worth noting that certain laboratory experiments and practical work may be conducted in abbreviated or demonstration formats [22]. To foster research skills, additional chemical experiments are essential, aiming to elucidate the underlying principles of the phenomena studied, encourage a creative problem-solving approach, and solidify theoretical knowledge through empirical confirmation [22].

The topic of "Solutions" occupies a central position in the study of chemistry, interconnected with vital domains such as inorganic and organic chemistry, chemical technology, and various types of reactions involving dissociation and ion exchange [19]. The prevalence and accessibility of solutions make them a unique object for students' learning research activities, enabling numerous classes to be organized as educational research experiences, encompassing both laboratory and applied home-based investigations.

Through the study of "Solutions", students not only acquire skills in handling chemicals and chemical equipment, including measuring instruments but also develop their abilities to observe, measure, calculate, and conduct experiments while making assumptions and formulating sound conclusions. Learning research activities offer students the opportunity to excel in these areas, facilitating a deeper understanding of the subject matter.

However, several challenges hinder the effective organization of learning research activities for students studying the topic of "Solutions". These challenges include limited time to conduct a substantial number of diverse experiments, particularly those of extended duration; shortcomings in the material support of school chemical laboratories, such as insufficient scientific equipment, potentially hazardous substances and precursors, and an inadequate supply of utensils; as well as limitations arising from students' physical abilities, health conditions, and individual characteristics, including their cognitive and mental development.

Addressing these challenges necessitates careful planning, innovative solutions, and the provision of adequate support and resources to ensure that students can engage in meaningful learning research activities while studying the topic of "Solutions" in chemistry. By doing so, educational institutions can foster students' research competence, critical thinking abilities, and scientific inquiry skills, empowering them to become lifelong learners and contributors to scientific progress.

2.3. Virtual chemical laboratories as a tools of teaching chemistry

Chemistry education at the school level often faces challenges in familiarizing students with real chemical objects and processes. These challenges arise due to limitations in school chemical laboratories, including equipment availability, restrictions on certain chemical compounds, time constraints within curricula, and other factors. To address these issues, the integration of information and communication technologies (ICT) in education has been proposed, specifically employing spreadsheets, augmented reality tools, and virtual chemical laboratories (VCL) [10, 11, 14].

A virtual laboratory is a hardware-software complex that allows experiments to be conducted without direct contact with a real installation or even in the absence of such an installation. There are two types of virtual laboratories: remote laboratories and simulation-based virtual laboratories [18]. Remote virtual chemical labs provide remote access to real lab equipment, either in real time or through video playback. They consist of a real laboratory with equipment and reagents, software and hardware for equipment control and data digitization, and communication tools to connect users with the lab setup. Simulation virtual laboratories, on the other hand, model relevant equipment, substances, and processes using computer-based simulations [18].

The utilization of VCL offers several advantages in chemistry education. Firstly, it eliminates the need to purchase expensive equipment and reagents, which can be a financial burden for many school chemical laboratories. Outdated equipment in these labs may distort experiment results and pose potential risks to students. While computer equipment and software also incur costs, their universality, wide distribution, and availability partially offset this disadvantage. Secondly, VCL allows the modeling of processes that are not feasible to observe in a traditional laboratory setting, such as those involving small particles or extreme conditions (e.g., ultra-high or ultra-low temperatures, pressure). Thirdly, VCL enables the observation of phenomena occurring at different time scales, ranging from fractions of a second to several years. Fourthly, VCL ensures the safety of students by eliminating immediate dangers associated with hazardous chemicals or devices involving high temperatures, pressures, or electric currents. Additionally, VCL saves time and resources by directly generating electronic-format results. Moreover, VCL facilitates informal education and distance learning, enabling students to perform chemistry laboratory work when access to physical labs is limited, such as during illness or quarantine periods. Lastly, VCL promotes the development of problem-solving skills, as it allows users to find optimal solutions and transfer real-world problems into model conditions and vice versa [5].

It is important to acknowledge that VCL represents a model of the real world and, thus, exhibits certain limitations and simplifications. Different VCLs vary in the level of detail in graphic representation, lack the ability to transmit smells or tactile sensations, and limit students' experience with real laboratory objects [12]. Virtual laboratories can be categorized based on visualization methods, including two-dimensional and three-dimensional graphics, as well as animation. They can also be classified based on the representation of subject knowledge. Some VCLs are based on pre-programmed experiments, providing a specific set of laboratory studies aligned with the curriculum, while others rely on mathematical models to simulate real chemical processes, allowing changes in experimental conditions and accurate representation of results.

Developing VCLs based on mathematical modeling is more complex and time-consuming but significantly expands their application possibilities [5]. Notable VCL software includes Yenka Chemistry, Model ChemLab, and Virtual Lab (VLab) [4, 8, 21]. Among these, Virtual Lab stands out as a freely available VCL with comprehensive features, making it suitable for the implementation of experimental problems.

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 [12].

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 [3].

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.

Simulation-based VCLs, exemplified by the ChemCollective Virtual Lab software, provide a comprehensive platform for students to engage in chemical experiments. Their ability to model complex processes, change experimental conditions, and provide instant feedback offers significant advantages over traditional laboratories. However, limitations such as the lack of sensory representation and the need for tailored laboratory works must be considered.

Remote VCLs enable students to observe real laboratory setups and conduct qualitative experiments. Their high-quality visualization of chemical processes contributes to a more realistic learning experience. However, quantitative experimentation may be limited due to the lack of interactive control over the process. Remote VCLs are best suited for learning new material, independent research, and knowledge assessment.

To support learning research activities in the study of "Solutions", a hybrid approach that combines simulation-based and remote VCLs is proposed. Simulation VCLs facilitate quantitative experiments and instant data analysis, while remote VCLs provide realistic representations of experimental details. By integrating these approaches, students can gain a comprehensive understanding of the subject matter.

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. Methodological framework for developing experimental problems in chemistry for grade 9 students using VLab, a cloud-oriented virtual chemical laboratory

3.1. Distinctive features of VLab, the virtual chemical laboratory

VLab stands out as one of the most accessible and user-intervenable modern Virtual Chemical Laboratories (VCLs). It empowers users to actively participate in virtual experiments and provides the capability to develop custom virtual laboratory assignments.

The primary objective of VLab, developed by the ChemCollective, is to create flexible and interactive learning environments that allow students to engage with chemistry as practicing scientists.

The Virtual Lab initiative began in 2000 as part of the IrYdium Project, which aimed to develop interactive and engaging educational materials linking chemical concepts to real-world applications.

Dr. David Yaron, a Professor of Chemistry at the Mellon College of Science, leads the project. The original exercises included in the virtual lab were meticulously crafted by a team at Carnegie Mellon University. This team consisted of Yaron, experienced software engineers, student programmers, educational consultants, and editors [2].

The Virtual Lab software is freely available for installation, use, and distribution. It can be utilized online by accessing the virtual lab plugin on the ChemCollective website using any web browser. Alternatively, users can download the installation files and install the program locally on their computers.

Furthermore, VLab can be seamlessly integrated with the Moodle learning management system using a dedicated plugin. This integration enables the application of individual virtual lab tasks within specific Moodle courses [10].

Each VLab assignment provides access to chemical reagents, including general-purpose reagents and compounds specific to the given task, as well as various chemical glassware (e.g., beakers, conical flasks, graduated cylinders, pipettes, volumetric flasks of different volumes, a 50 ml burette, and plastic cups) and equipment (e.g., Bunsen burner, weighing hook, and scales).

The program interface incorporates a dedicated panel that furnishes substance or mixture-related information, such as name, volume, state of aggregation, amount of substance (in moles or grams), concentration (in moles per liter or grams per liter), spectrometer data, pH meter readings, and thermometer readings. Some of these tools can be enabled or disabled based on the problem's requirements in the virtual laboratory setting (figure 1).

Interactions with apparatus and substances within the virtual lab are executed using a drag-and-drop mode, where objects can be manipulated simply by dragging them with the left mouse button. Additionally, specific actions and general operations can be accessed through the menu that appears upon right-clicking an object [20].

The essence of the program revolves around accessing and solving specific problems experimentally or through calculations, with subsequent verification through practical experimentation. There are no restrictions on the number of attempts to perform an experiment or on the use of specific quantities of reagents and materials.

According to the developers, utilizing the exercises within VLab enables:

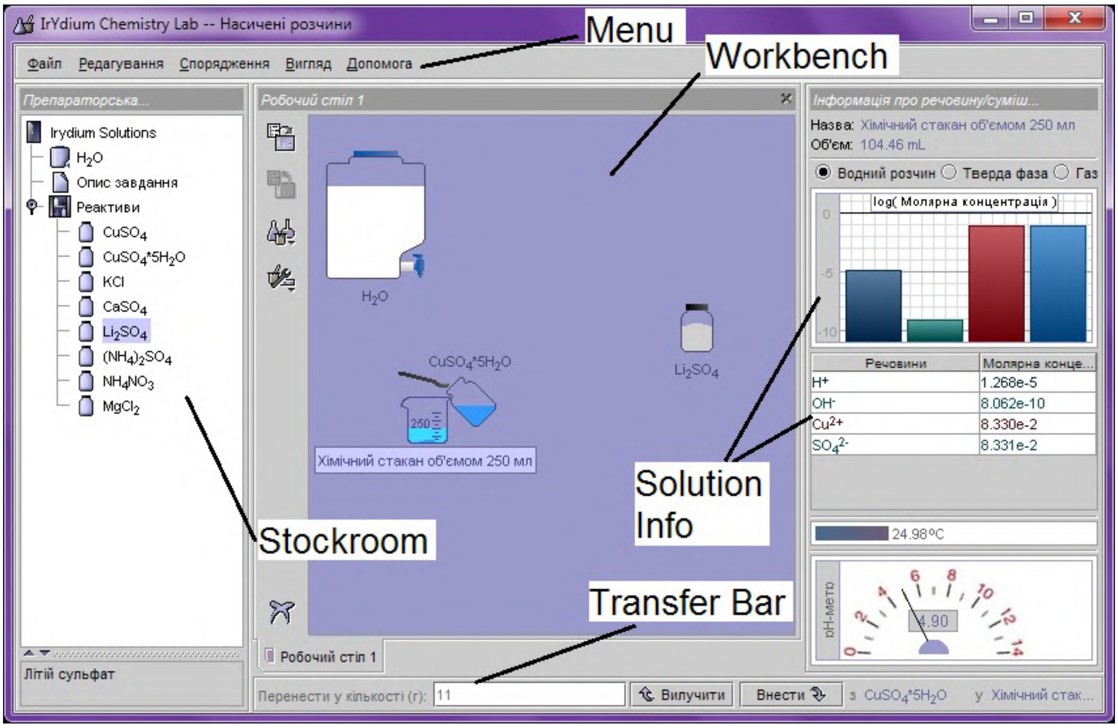

Figure 1: VLab window with virtual laboratory work.

- students who have missed laboratory work to conduct experiments from their personal computers without requiring direct supervision from a teacher;
- supplementation of traditional paper-based assignments and homework with exercises that allow students to employ chemical concepts in designing and executing their own experiments;
- monitoring of students' assignment accuracy, as they can use the virtual laboratory to validate their own calculations or qualitative predictions without any risk to their safety;
- augmentation of classroom demonstrations by allowing teachers to showcase chemical processes in a physical laboratory setting, followed by independent exploration of the chemical system and processes by students guided by the virtual lab problems.

Currently, the Virtual Lab software includes over 50 exercises and problems aimed at reinforcing chemical concepts, particularly those related to the study of solutions and associated processes. These topics encompass molar quantities, stoichiometry and limiting reagents (including problems involving excess reagents), density, dilutions, dissociation constants, acids and bases, thermochemistry, solubility, chemical equilibrium, and redox processes [3].

The Virtual Lab installation package comprises thirteen launch files, available in different languages. Since 2014, Ukrainian has been one of the supported languages. The previous versions of the program, both online and local, required the presence of a Java plug-in. However, most browsers and antivirus programs now block this plug-in, necessitating separate system settings. Consequently, in 2017, an HTML5 version of VLab was launched on the ChemCollective website, which currently supports English, Spanish, and Italian languages only.

A special problem editor, called the Virtual Lab Authoring Tool, can be downloaded from the old version of the ChemCollective website (http://collective.chem.cmu.edu). This tool enables modification of existing problems and the creation of new problems specifically for the local version of the program.

The problem set included in the standard version of VLab mostly targets core, college, or university levels, surpassing the scope of basic school requirements. However, a significant portion of the problem content is structured to serve as comprehensive study and research problems [10]. In our work, we aim to develop experimental chemical problems specifically for the "Solutions" topic that align with the curriculum and are suitable for primary school students in terms of complexity.

3.2. Designing laboratory activities in VLab: a virtual chemical laboratory

To create customized laboratory activities in VLab, a thorough understanding of its functionality is necessary. VLab is a virtual laboratory software that can be launched by executing the default.xml file (or default_uk.xml for the Ukrainian version) found in the assignments directory. This file serves as the default virtual lab template and includes various settings for the program's working environment. These settings determine the availability of tools (e.g., thermometer, pH meter, windows with substance information) and the modes of substance transfer (e.g., accurate transfer, rounded quantities, realistic transfer). Depending on the requirements of the laboratory activity, specific tools and transfer modes can be enabled or disabled. The default.xml file also specifies the reagents, physicochemical processes, problem descriptions, and other relevant details. The paths defined in the default.xml file point to files located in a subdirectory with the same name as the control XML file. For example, the default_uk.xml file guides the program to the default_uk directory (located in the program directory assignments/default_uk). This directory contains four essential files:

- filesystem.xml: This file provides information about the planned reagents and their properties (e.g., concentration, volume or mass, brief description) for the virtual laboratory activity.
- reactions.xml: It contains information about all the possible chemical reactions involving the selected set of substances for the virtual laboratory activity.
- species.xml: This file includes information about all the substances available in the virtual laboratory activity, along with their properties (e.g., color, state of aggregation, thermodynamic parameters, molar mass).
- problem_description.html: It contains a textual description of the laboratory activity problem and instructions for conducting the virtual lab work.

In VLab versions higher than 2.1.0, an additional file called spectra.xml may be present. This file includes the spectral characteristics of substances that will be displayed in the photocolorimeters window, if applicable to the laboratory activity.

To initiate other laboratory activities, the same principle is followed, but the control XML files are located in separate thematic sub-subdirectories within the language localization subdirectories. For instance, the control XML file for the localized Ukrainian work "Determining the solubility of $CuCl_2$ at different temperatures", named CuClSolu.xml, is located at assignments/problems_uk/solubility.

The list of control XML files, along with their paths and brief descriptions, is stored in the ProblemIndex_uk.xml file (ProblemIndex.xml for the standard English version) in the root directory of the program. This file allows the user to access the available laboratory activities through the "File" → "Load problem" menu.

Editing any of these files is possible using a text editor like Notepad (important to save changes in UTF-8 encoding) or an XML file editor. However, for optimal results, the Virtual Lab Authoring Tool, a dedicated editor, is recommended. The tool offers several options for creating new laboratory activities, such as starting from scratch, editing and saving the default XML file, or basing it on an existing activity. The latter option is faster and more efficient since it allows the reuse of reagents, equipment, and other parameters already entered into the system. To make changes using this approach, open the control XML file in the Virtual Lab Authoring Tool editor and select "Save As..." from the "File" menu. Specify the new file name and location. In this case, a separate directory named School was created specifically for this set of activities, and it automatically generates the corresponding content files.

To customize and refine virtual laboratory activities, the control XML file within the Virtual Lab Authoring Tool serves as a pivotal element for editing. The tool offers an intuitive interface with multiple tabs, each dedicated to modifying specific aspects of the activity (figure **??**):

- General: This tab allows users to input the title of the activity, the author's name, and a concise description of the content.
- Permissions: Under this tab, users can define the available tools for viewing substance properties and chemical compositions (Viewers), as well as determine the parameters for substance transfer (Transfer Bars) within the activity.
- Species: This tab provides tools for creating and editing the substances required for the activity. Along with the formula, molar mass, and name of the substance, mandatory characteristics such as state of aggregation, coloring parameters, standard enthalpy of formation, and entropy are specified. These data are crucial for simulating chemical reactions between the substances.
- Reactions: In this tab, users can plan and organize the flow of physicochemical processes by defining reactive particles as reagents or reaction products and setting appropriate coefficients.
- Stockroom: This tab empowers users to create and edit the contents of the virtual laboratory's "Stockroom." It enables the addition of cabinets, dishes with reagents, and accompanying files (e.g., problem descriptions).

Once the editing process in the Virtual Lab Authoring Tool is complete, it is essential to save the changes and include the newly created activity in the registry for it to be accessible. This can be achieved by adding a block in the ProblemIndex_uk.xml file using a text editor or XML editor:

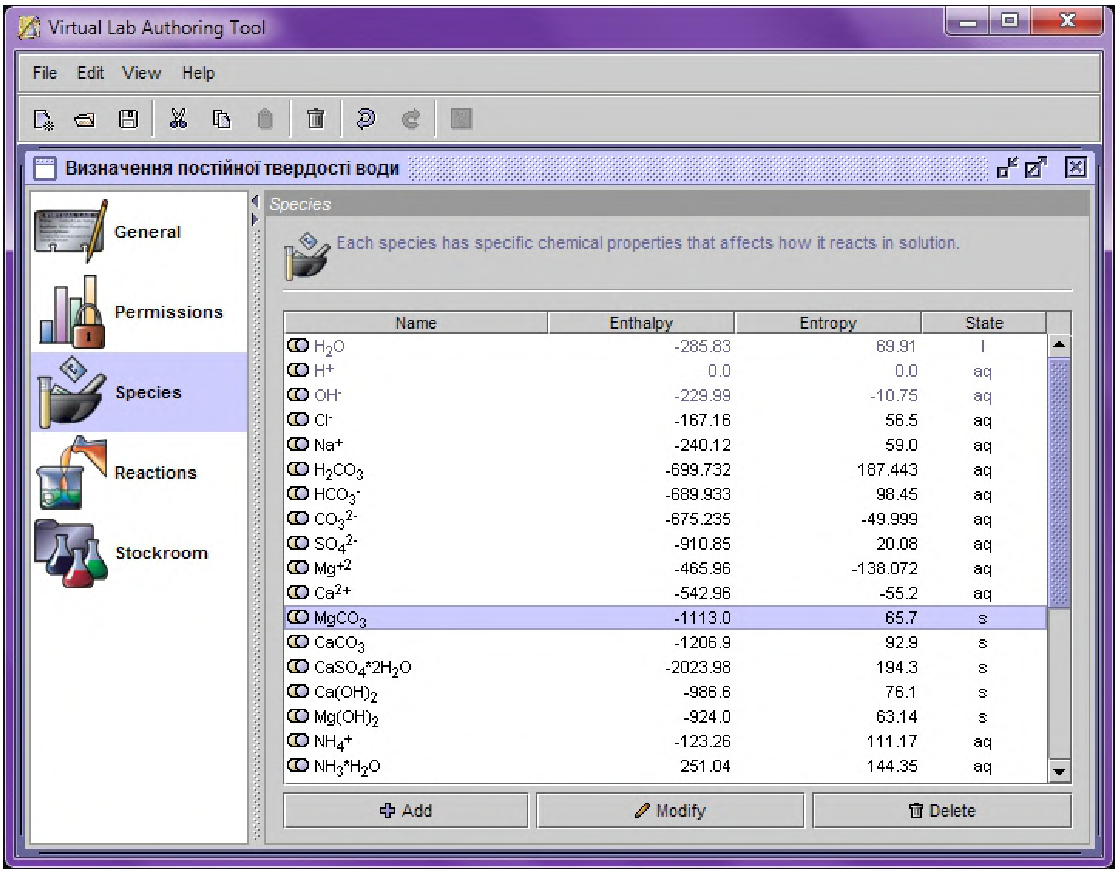

Figure 2: The Virtual Lab Authoring Tool window.

```
<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>
```

The <DIRECTORY> tags enclose a block that can contain multiple individual activities, each separated by <PROBLEM> tags.

Upon the next program launch, the newly created or edited activities will become available for use.

3.3. A set of experimental chemical problems in a virtual chemistry lab VLab for use in school when studying the topic "Solutions"

The topic of "Solutions" holds significant importance in the grade 9 chemistry curriculum [19]. It involves solving experimental and computational problems related to solutions with specific solute mass fractions, conducting demonstration experiments to explore thermal phenomena during dissolution, studying substances and their aqueous solutions' electrical conductivity, and engaging in laboratory investigations. These investigations encompass activities such as detecting hydrogen and hydroxide ions in solutions, determining approximate pH values of water, alkaline and acidic solutions using a universal indicator, exploring pH in cosmetic and personal care products, conducting exchange reactions between electrolytes in aqueous solutions accompanied by precipitation, detecting chloride, sulfate, and carbonate ions in solution, and conducting ion exchange reactions between electrolytes in aqueous solutions. Additionally, students are encouraged to carry out practical work, home experiments, and educational projects on topics like preparing colloidal solutions, studying electrolytes in modern accumulators, growing salt crystals, preparing medical assistance solutions, analyzing soil pH, investigating the influence of soil acidity and alkalinity on plant development, exploring the pH of atmospheric precipitation and its impact on various materials, investigating natural objects as acid-base indicators, and analyzing the pH of mineral water in Ukraine.

Among the various aspects of this topic, understanding the solubility of substances and its dependence on various factors, as well as comprehending saturated and unsaturated solutions, concentrated and diluted solutions, and thermal phenomena associated with dissolution, play a crucial role. Other key concepts include the concept of hydrates, electrolytic dissociation, and the use of qualitative reactions and indicators. Consequently, experimental problems should be designed to focus on these significant components of the topic.

After a thorough analysis of the technical and visual capabilities of the VLab, we have identified that creating virtual experimental problems specifically related to the dissolution process (including its energy and quantitative characteristics), substance dissociation in solutions with pH determination, and utilization of qualitative reactions and indicators would be most appropriate. However, certain experiments exploring properties of colloidal solutions, specific exchange reactions, crystal extraction, and qualitative reactions resulting in precipitation formation cannot be replicated due to the limited modeling possibilities for chemical phenomena in the VLab and the constraints of visual representation. For instance, conducting qualitative reactions with sediment formation necessitates an adequate number of test tubes, and the visibility of sediment and its color can only be accurately perceived in quantities of a few grams or more, which does not align with the principles of qualitative chemical analysis.

Considering these factors, we have developed a preliminary set of experimental problems focused on the "Solutions" topic, comprising seven distinct problems. Each problem includes instructions for problem-solving and a series of questions that students are required to answer.

For example, the laboratory work titled "Precursor" tasks the student with assuming the role of a laboratory technician and conducting dilutions of concentrated sulfuric acid, which is categorized as a precursor. The objective is to prepare equal volumes of solutions with specified concentrations.

Another problem, "Separation of salt mixture", involves separating a mixture of crystalline potassium chlorate and sodium chloride through recrystallization of potassium chlorate based on the difference in solubility between these salts. The problem presents a sequential set of actions to guide students through the experiment. The purpose of this problem is to familiarize students with purification and separation methods for substances and demonstrate the temperature-dependence of salt dissolution.

To explore the preparation of saturated solutions, the problem "Preparation of saturated solutions of various chemical compounds" can be employed. Here, students can prepare solutions while varying the temperature and subsequently construct concentration-temperature curves for saturated solutions of different substances. The objective is to study the solubility change of substances with temperature, develop skills in preparing saturated solutions, and analyze experimental data.

The investigation of thermal effects during dissolution can be carried out through the problem "Thermal effects of dissolution". The problem description highlights that dissolution involves various physical and chemical processes in both the solute and solvent. One easily observable external indicator of these processes is the thermal effect experienced during the dissolution of different substances. Students are tasked with investigating the thermal effects of dissolving various crystalline compounds in water and drawing appropriate conclusions and assumptions regarding the underlying processes. This problem aims to deepen students' understanding of the thermal phenomena accompanying dissolution, allowing them to test their knowledge practically and consolidate their understanding of exothermic and endothermic processes.

Each problem in the set includes sufficient hints to enable students to independently conduct experiments in the virtual laboratory, such as on their home computers. Some problems can even be replicated in real school chemistry laboratories given the necessary time and resources. In such cases, solving problems in the virtual laboratory can serve as a training option to verify theoretical calculations and practice the required procedures.

The collection of these laboratory works is available on the website of the Department of Chemistry and Methods of Learning Chemistry at Kryvyi Rih State Pedagogical University (https://kdpu.edu.ua/khimii-ta-metodyky-ii-navchannia/tsikava-khimiia/dlia-vseznaiok/5928-virtualna-khimichna-laboratoriia.html). This initiative aims to introduce these virtual laboratory works into schools' educational processes and gather feedback to enhance and expand the set's quality.

4. Design and implementation of a virtual chemical laboratory for investigative learning in chemistry: a case study on the "Solutions" topic

The educational approach adopted in the virtual laboratory (VLab) for the "Solutions" topic revolves around research-oriented problem-solving tasks. These tasks present students with specific objectives that fall into two categories:

1. *Achieving practical results*: In this scenario, students are encouraged to develop their own algorithms and verify their efficacy through practical experimentation within the virtual

environment. The trial-and-error method is a valid approach for students to explore different pathways towards obtaining the desired outcomes.

2. *Exploring unknown processes and phenomena*: The second type of task involves studying processes and phenomena whose properties are unfamiliar to the students. By completing these tasks, students have the opportunity to discover new patterns, properties, and relationships. Drawing conclusions based on the results obtained in the virtual chemical laboratory empowers students to understand the influence of various factors on the dissolution process. These findings can then be compared to information found in textbooks or conveyed by their teachers.

The virtual laboratory offers abundant prompts and instructions within the problems, enabling students to engage in independent experimentation. They can easily conduct these experiments on their personal computers, even from the comfort of their homes. Moreover, some of the problems are designed to be replicable in real educational chemical laboratories, allowing students to verify theoretical calculations and practice the required procedures.

While the VLab platform facilitates independent experimentation with substances and solutions, it is not specifically tailored for qualitative reactions. Qualitative reactions prioritize clear and accurate visual indicators, which may be challenging to replicate faithfully within a virtual environment. Recognizing this need, we developed a dedicated resource to support qualitative chemical experiments—the remote virtual chemical laboratory.

The essence of this remote virtual chemical laboratory is to provide users with remote access to a comprehensive range of substances necessary for conducting high-quality laboratory experiments. To ensure an optimal user experience, we considered various user actions, including accidental or illogical ones. Consequently, the program interface incorporates two sets of reagents, allowing users to mix any reagent from the first set with any reagent from the second set. Upon selecting a suitable reagent pair, a brief video recording depicting the mixing process in a real chemical laboratory is triggered. Users cannot modify the number of reagents or the order of their addition. However, they have the freedom to observe the high-quality visualization multiple times, accompanied by a textual description of the underlying reaction.

To make the virtual chemical laboratory widely accessible, we deployed it on the internet through a dedicated website. The laboratory interface is essentially an HTML page, encompassing JavaScript elements, videos, codes, and other essential components related to each laboratory work. By structuring the website accordingly, we ensure the smooth operation of the remote virtual chemical laboratory, providing users with a seamless and engaging learning experience.

Figure 3 illustrates the key elements comprising the site of the laboratory installation with remote access, encompassing JavaScript, video, and code components, among others.

The remote virtual chemical laboratory developed by our team consists of several objects distributed across different directories:

- The “favicons” folder contains favicon elements, which serve as site icons for various browsers.
- The “js” folder stores JavaScript files responsible for providing dynamic interactivity on the website.

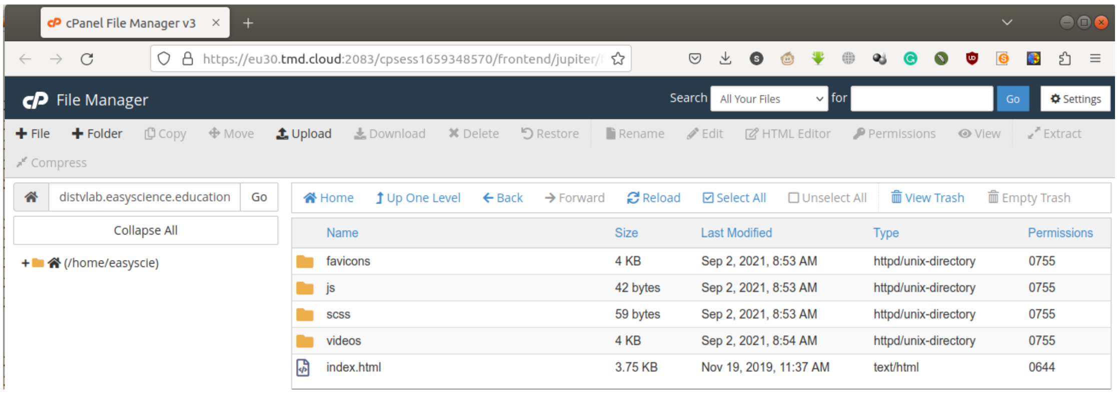

Figure 3: Key elements of the laboratory installation with remote access site.

- The “scss” folder contains style files that determine the external design and stylization of the site page.
- All experiment videos recorded for website integration are saved in the “videos” folder.
- The main file, “index”, houses the primary startup code of the laboratory and plays a central role in its functioning.

The online page for accessing the virtual chemical laboratory involves the execution of specific program code, which can be edited by connecting to an FTP server and utilizing tools such as Notepad++ or an XML editor.

The primary operation of the initial virtual laboratory, focusing on the "Indicators" topic, follows a general principle. Users select buttons located in the upper left corner to choose an indicator and a solution with a particular acidity level. Pressing the "show" button triggers the playback of videos illustrating the color change of the solution during the first reaction (figures 4 and 5).

Figure 4 showcases the placement of the main element buttons within the remote laboratory.

Figure 5 demonstrates the operation of the remote chemical laboratory, specifically highlighting the selection of the “Phenolphthalein” and “Solution No 5” buttons.

To return to the indicator and solution selection, users can press the “Clear” button located in the middle on the left and start the selection process again.

The second laboratory work, labeled as “Lab 2”, is based on an experimental problem involving “Qualitative reactions to the most common anions”. Its overall operation principle aligns with that of the “Indicators” virtual chemical laboratory. Users select buttons located in the upper left corner to choose solutions of reagents such as $AgNO_3$, $Pb(NO_3)_2$, and $BaCl_2$, and a solution containing an unknown anion that students must determine. By pressing the “Show” button, a video showcasing the chemical reaction between the selected solutions is initiated.

It is important to note that both laboratory works can serve as research-oriented tasks. The “Indicators” lab encompasses indicators beyond those typically described in textbooks, such as bromocresol purple, congo red, and red cabbage juice. Consequently, working with these indicators offers an opportunity for research-oriented exploration. The “Qualitative reactions

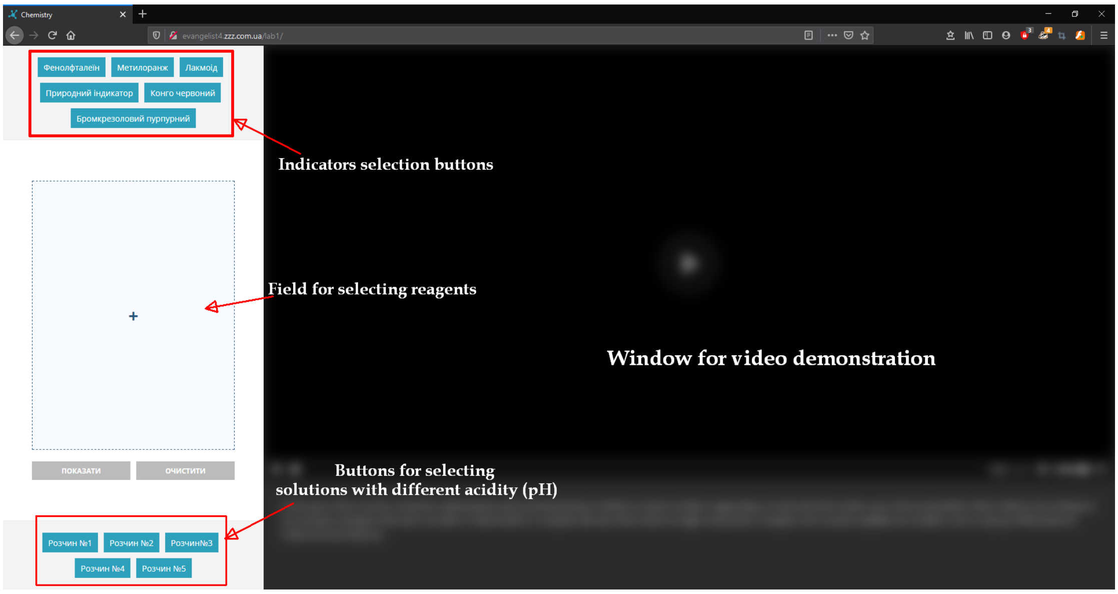

Figure 4: Button placement of key elements within the remote laboratory.

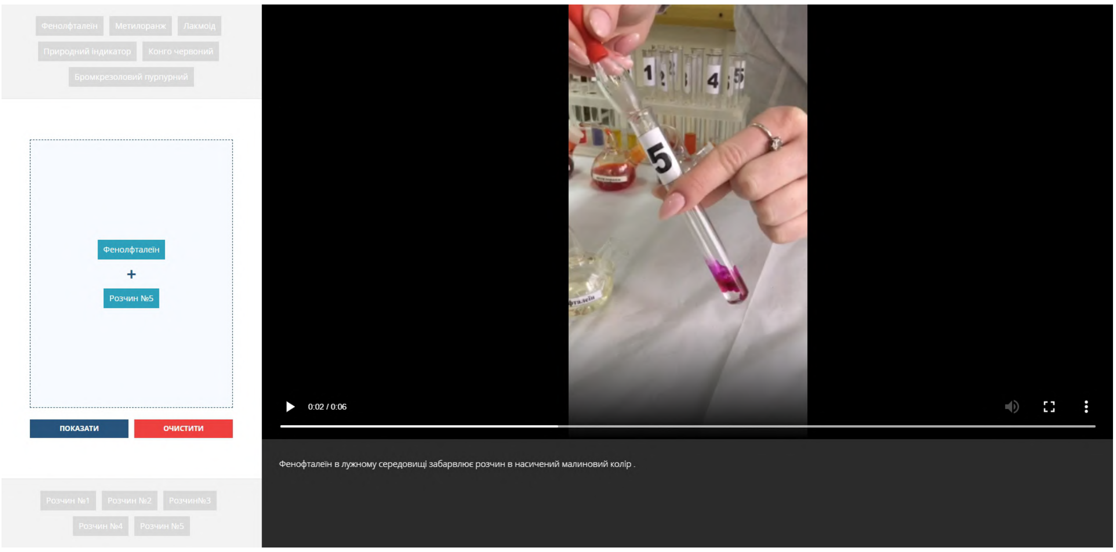

Figure 5: Operation of the remote chemical laboratory: Selection of “Phenolphthalein” and “Solution No 5” buttons.

of some anions” work, on the other hand, primarily serves as an experimental problem for the identification of anions.

Both laboratory works are available on the website http://distvlab.easyscience.education/ and can be accessed directly through the following links: http://distvlab.easyscience.education/Lab1 and http://distvlab.easyscience.education/Lab2.

5. Results

The effectiveness of the developed virtual laboratory works was evaluated through testing conducted during chemistry lessons and optional classes in multiple educational institutions in the city of Kryvyi Rih during 2019. The participating institutions included Kryvyi Rih Central City Lyceum, Kryvyi Rih Central City Gymnasium, schools No 66 and No 21, as well as Kryvyi Rih College of National Aviation University of Ukraine. The virtual chemical laboratories were accessed using various devices such as personal computers, netbooks, SMART Board interactive whiteboards, smartphones, and tablets.

Chemistry teachers praised the convenience of the virtual chemical laboratories, noting their usefulness in preparing for laboratory work or serving as partial replacements. Furthermore, they found that the virtual labs effectively facilitated independent student work.

To gather feedback from the students, a questionnaire consisting of the following questions was administered:

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 practical work?"
5. "What did you like most about using virtual chemistry labs while studying chemistry?"

A total of 144 students participated in the survey. The results are presented in table 1.

Table 1
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%)

For the fifth question, which allowed open-ended responses, students frequently mentioned aspects such as "non-standard approach to lesson organization", "unusual and novel use of virtual chemical laboratories", "freedom to conduct experiments without time constraints or strict accountability for individual actions", "opportunity for independent experimentation based on personal interests", and "ability to catch up on missed lessons by preparing at home". According to the observations of participating teachers, the use of virtual chemistry laboratories increased students' eagerness to experiment and reduced their fear of making mistakes or drawing erroneous conclusions during experiments. This positive effect was reflected in the high performance demonstrated by students in practical work and experimental problems related to the "Solutions" topic.

In summary, the majority of students expressed positive perceptions of the Virtual Chemical Laboratories (VCL), particularly in terms of preparing for practical work. A slightly lower percentage of students also found value in using VCL for acquiring theoretical knowledge. The novelty and non-standard approach of VCL made it an engaging learning tool for the vast majority of students. However, a smaller percentage noted initial challenges with ease of use, likely stemming from the novelty of these teaching tools and the need to develop proficiency in their usage.

6. Conclusions

The findings from this study shed light on the importance of incorporating learning research activities, particularly in the field of natural sciences, as an integral part of a quality educational process. Learning research activities differ from traditional learning approaches by emphasizing an active cognitive stance, internal exploration to seek answers, creative information processing, and trial-and-error approaches. These activities, distinct from scientific research, yield subjective acquisition of new knowledge, development of research skills, and cultivation of other valuable traits in students.

One notable type of learning research activity in chemistry is experimental chemical problems, which necessitates practical implementation of chemical experiments. Experimental chemical problems exhibit methodological feasibility across various lesson types, different stages of a lesson, and extracurricular work.

Among the pivotal topics covered in the school chemistry curriculum, the “Solutions” topic holds immense significance. It serves as a crucial point of consolidation for general and inorganic chemistry knowledge, equips students with essential experimental skills, and lays the theoretical and practical foundation for further chemistry studies.

Pre-profile chemistry training entails a significant amount of student experimentation. Virtual chemical laboratories offer a viable solution to address the challenges posed by limited time, inadequate equipment, and scarcity of reagents. These computer programs enable the simulation of physical-chemical phenomena and the execution of experiments without direct interaction with a real chemical set, or in cases where conducting a real experiment is unfeasible.

Virtual chemical laboratories primarily function as unique simulators, allowing users to test action algorithms, trace the logical sequence of laboratory operations during an experiment, practice data collection and recording skills, and analyze experimental results. Remote virtual chemical laboratories excel in qualitative experiments, while simulation-based virtual chemical laboratories specialize in quantitative chemical experiments. In certain situations, virtual chemical laboratories can serve as substitutes for real chemical experiments when implementation is impractical.

By utilizing virtual chemical laboratories, research competencies of students can be developed safely and economically through the execution of experimental chemical problems, which can be conducted entirely in a virtual setting or initially practiced in a simulated environment before implementing them in a real experiment.

Virtual chemical laboratories are highly versatile learning tools applicable at various stages of a lesson, including introduction, new knowledge acquisition, knowledge consolidation, and assessment. They can also be utilized for independent study and homework assignments. When properly integrated into the learning process, virtual chemical laboratories empower students to engage in learning research activities at their convenience and in any location.

For optimal support of learning research activities in chemistry, particularly when addressing experimental chemical problems within the "Solutions" topic, a combination of two types of virtual chemical laboratories is recommended: remote laboratories for qualitative experiments and simulation laboratories for quantitative experiments.

The development of virtual laboratory works, comprising seven problems in the simulation-based Virtual Lab and two experimental problems in the remote virtual chemical laboratory, has been accomplished. These virtual laboratory works were introduced into the educational process of multiple institutions in Kryvyi Rih (Ukraine) and received predominantly positive feedback from both chemistry teachers and students. This suggests that virtual chemical laboratories possess substantial potential for organizing and enhancing learning research activities in chemistry, specifically within the context of the "Solutions" topic. Further improvements should be pursued based on the outcomes of their implementation in the school educational process.

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