

TEACHING TITRIMETRIC ANALYSIS THROUGH DIGITAL EDUCATIONAL TECHNOLOGIES: THE EXAMPLE OF THE CHEMCOLLECTIVE PROGRAM

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Abstract

This article analyzes the capabilities of the ChemCollective virtual laboratory in teaching one of the main branches of analytical chemistry titrimetric analysis (acid-base and redox titrations). The platform helps reinforce students' theoretical knowledge, develop practical skills, and effectively conduct laboratory sessions even in remote learning environments.

Keywords: Analytical chemistry, titrimetric analysis, acid-base titration, redox titration, ChemCollective, virtual laboratory, digital education technologies, distance learning.

Introduction

In the 21st century, digital technologies have been rapidly penetrating all spheres of human life, particularly the education system. Digital transformation is not limited to the use of technical tools; it also involves a fundamental renewal of the content, methods, and forms of education. In modern education, interactivity, flexibility, visualization, and the possibility of distance learning are ensured precisely through digital technologies. Today's learners and students, often referred to as "Generation Z," have grown up in a digital environment and are accustomed to receiving information quickly, conveniently, and in multimedia formats. Therefore, the use of engaging, motivating, and relevant digital tools in the educational process has become a requirement of the time.

Moreover, digital educational technologies have several advantages. These include flexible learning, where each learner can study at their own pace; unlimited access to resources, meaning the opportunity to study anytime and anywhere via the internet; increased learner engagement through interactive tasks, tests, and gamified elements, which strengthen motivation; and the ability

for teachers to monitor and analyze learners' progress through online tracking systems. In addition, particularly in the natural sciences, digital tools enable laboratory experiments to be carried out virtually through simulations without the need for real equipment (for example, ChemCollective).

For this reason, the Presidential Decree of the Republic of Uzbekistan No. PQ–4851 of October 28, 2020, identified the development of digital education as one of the priority directions. Within the framework of the “Digital Uzbekistan – 2030” strategy, key objectives have been set to widely implement information and communication technologies in higher education, establish remote and hybrid teaching systems, create digital content, and integrate it into the educational process. Thus, digital educational technologies have become an integral part of modern education. They not only improve the quality and efficiency of education but also make learning more personalized, open, and innovative for students. Virtual tools, in particular, provide a modern alternative solution for teaching laboratory methods.

In modern education, creating an interactive, safe, and cost-effective environment for teaching analytical chemistry—especially titrimetric analysis—is of particular importance. From this perspective, the ChemCollective platform stands out as one of the most convenient virtual laboratories available today. ChemCollective is an online laboratory environment developed by Carnegie Mellon University and offered free of charge to educational institutions, teachers, and students. Its main purpose is to provide a digital, interactive format for practical chemistry learning. The technical capabilities of this program include:

- a) Virtual laboratory environment;
- b) Chemical glassware (flasks, pipettes, burettes);
- c) A set of reagents (acids, bases, indicators, standard solutions);
- d) Measuring tools (mass measurement, volume determination, pH indicators);
- e) Preparation of mixtures and observation of reactions in real time;
- f) The ability to calculate reaction equilibria, pH changes, and solution concentrations;
- g) Obtaining experimental results in graphical and tabular form;
- h) Remote access, meaning it can be used on any device connected to the Internet.

In addition, the program offers the following methodological opportunities:

- a) Conducting lessons based on didactic scenarios;

- b) Practical exercises that reinforce theoretical knowledge;
- c) Developing skills in analysis, hypothesis formulation, and drawing conclusions through experiments;
- d) Independent inquiry-based research on the basis of problem situations (inquiry-based learning);
- e) A differentiated approach through interactive assignments;
- f) Creating a collaborative experimental environment with active student participation.

The ChemCollective platform is particularly convenient for simulating titration methods in digital form and is highly suitable for studying the following topics:

1. Acid-base titration (for example, using HCl and NaOH solutions);
2. Redox titration (using KMnO_4 and $\text{H}_2\text{C}_2\text{O}_4$);
3. Complexometric titration (determining Ca^{2+} and Mg^{2+} with EDTA);
4. Observation of pH indicators and titration curves.

This virtual platform allows students to study all stages of the titration process step by step. For example, in acid-base titration, they can perform the standardization process using NaOH and HCl solutions, select indicators, and analyze the titration curve by observing pH changes. In redox titration, the simulation clearly demonstrates the oxidizing properties of KMnO_4 and the steps to determine the amount of $\text{H}_2\text{C}_2\text{O}_4$. Through these processes, students learn to properly select necessary glassware and reagents, accurately perform titration techniques, record results digitally, construct graphs, draw conclusions, analyze errors, and develop self-assessment skills.

Thus, with the help of the ChemCollective platform, students can acquire solid knowledge and practical skills through safe, low-cost, convenient, and repeatable experiments without the risks present in traditional laboratory conditions. This vividly demonstrates the effectiveness of modern digital teaching tools.

In this study, to assess the effectiveness of teaching titrimetric analyses (acid-base, redox, and complexometric) through virtual laboratories based on the ChemCollective platform, lessons were conducted in both an experimental group and a control group. Classes for the experimental group were carried out using ChemCollective simulations, while classes for the control group were conducted using traditional laboratory methods. The experiment lasted for three weeks and was carried out in two stages:

Stage 1: Both groups received theoretical instruction on titrimetric analyses.

Stage 2: Practical lessons—conducted using virtual simulations for the experimental group and in a traditional laboratory for the control group.

At the end of the experiment, students were evaluated based on the following criteria:

1. Accuracy in completing practical tasks (selection of reagents, titration technique);
2. Construction and analysis of titration curves;
3. Drawing conclusions and presenting results graphically;
4. Self-assessment and error analysis.

The results are presented in the following table.

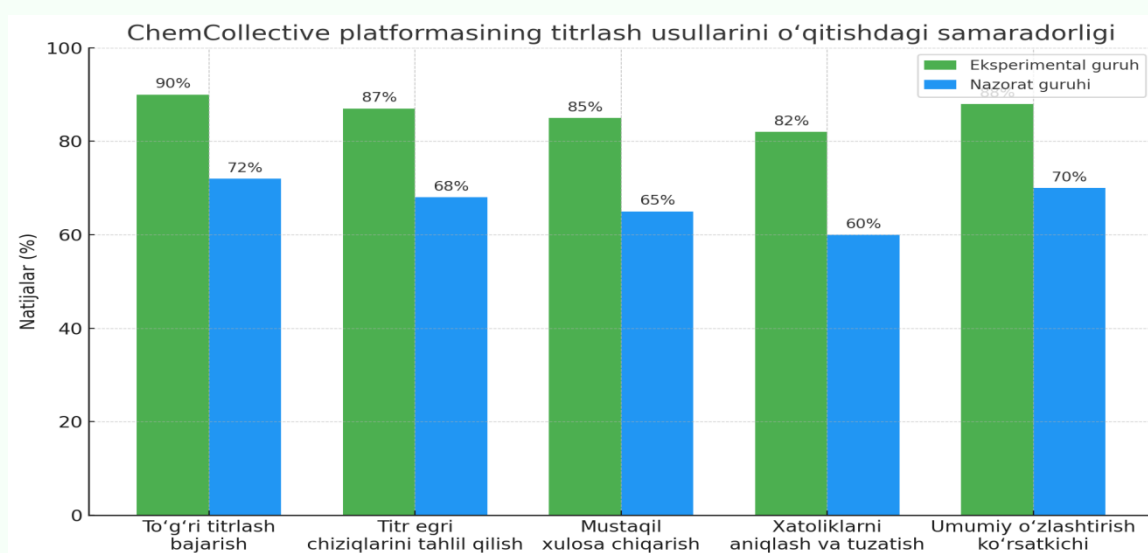
Table 1

Assessment criteria	Experimental group (ChemCollective)	Control group (Traditional)
Correct performance of titration (%)	92%	76%
Analysis of titration curves	88%	70%
Independent conclusion-making	85%	68%
Error identification and correction	80%	61%
Overall achievement rate (%)	86.2%	68.7%

The analysis of the results presented in Table 1 shows that the digital learning environment organized through the ChemCollective platform has effectively contributed to the development of students' knowledge and skills. In particular, the ability to correctly perform titration reached 92% in the experimental group, which is significantly higher compared to 76% in the control group. Similarly, students in the experimental group achieved higher results in analyzing titration curves, identifying and correcting errors, and making independent conclusions. These differences indicate that the ChemCollective platform, with its interactive and visual tools, helped students gain a better understanding of complex chemical processes, actively engaged them in practical tasks, and enhanced their analytical thinking skills. In addition, the use of digital simulations allowed students to repeatedly review, analyze, and correct mistakes, which directly improved their overall performance.

The following diagram visually analyzes the effectiveness of teaching titrimetric analyses using the ChemCollective platform. It clearly illustrates the differences between the experimental and control groups in terms of correct titration performance, curve analysis, independent conclusion-making, error identification, and overall achievement.

The diagram clearly demonstrates that students who were taught using the digital platform achieved higher results across all criteria compared to the group taught using traditional methods. This provides practical evidence of the effectiveness of the digital approach.



(Diagram 1)

This diagram compares the results of the experimental group, which used the Chem Collective platform, with those of the control group, which was taught using traditional methods. The assessment criteria included correct execution of titration, construction and analysis of titration curves, independent conclusion-making, identification and correction of errors, and overall learning achievement. The analysis of the diagram shows that the experimental group achieved 90% accuracy in performing titration, whereas the control group achieved 72%. For constructing and analyzing titration curves, the experimental group reached 87%, which is significantly higher than the 68% of the control group. In terms of independent conclusion-making, the experimental group achieved 85%, compared to 65% in the control group. Similarly, the skills of identifying and correcting errors were 82% in the experimental group versus 60% in the control

group. Overall learning achievement was 88% in the experimental group and 70% in the control group.

These results show that a learning model based on digital simulations is more effective than traditional approaches for deepening students' knowledge, developing analytical skills, and improving their ability to work independently in practical activities. Based on these findings, it can be concluded that digital instruction (specifically, using ChemCollective) leads to significantly higher levels of practical and analytical skills compared to traditional methods.

In addition, students expressed the following positive reflections in their final feedback forms:

- “The virtual experiment was safe and easy to understand.”
- “The option to go back and review each stage helped me a lot.”
- “My knowledge of colors, pH values, and indicators became more solid through practice.”

This demonstrates that teaching with modern digital technologies not only improves the effectiveness of education but also increases student engagement.

From the results of this study, the following conclusions can be drawn:

- The use of digital educational technologies plays an important role in teaching analytical chemistry, especially in developing knowledge and skills related to titrimetric analysis.
- Organizing sessions through virtual platforms such as ChemCollective creates a safe, interactive, and self-directed learning environment for students.
- These platforms, through visual tools and step-by-step guidance, help students deeply understand chemical processes.
- Digital simulations allow repeated practice, fostering analytical thinking, problem-solving, and the ability to draw conclusions.
- This approach strengthens students' knowledge at an analytical and reflective level, rather than a superficial one.
- Furthermore, the use of digital tools in the learning process helps students develop digital competencies, which raise their professional preparedness to modern standards.

The increased interest in chemistry and the improved level of learning demonstrate the positive effectiveness of the digital approach. The study results show that organizing laboratory activities in a blended learning format—combining traditional laboratory work with virtual instruction—ensures the

transformation of theoretical knowledge into practical skills. This approach is an important factor in deepening students' knowledge, motivating them to work independently, and improving the quality of education.

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