



Development of a Virtual Laboratory with a Project for Teaching Complexometric Titration to Improve Learning Outcomes

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Abstract

The teaching of complexometric titration has not yet utilized learning media that can foster student activity, so that, in terms of cognition, students' abilities remain low. Another problem was that experiments in complexometric titration were not conducted due to limited practical work time following the implementation of block learning. The purpose of this study is to develop a virtual laboratory project to teach complexometric titration and improve student learning outcomes. This research is a Research and Development study using the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). This study involved 72 students from two classes of the Chemistry Education study program in the 2023-2024 academic year. The research instruments used were a virtual laboratory feasibility questionnaire, a test, and a response questionnaire. The results showed that the virtual laboratory media had a feasibility of 87.22%, indicating it is highly feasible for use. Student learning outcomes from objective tests showed that the N-Gain in the class was 0.68, a significant increase compared to the control class's 0.55. The student response to the development of the virtual laboratory project is 87.65%, which falls in the very good category. Therefore, it can be concluded that developing a virtual laboratory with projects is highly feasible for use in complexometric titration instruction to improve student learning outcomes.

Keywords: Complexometric titration; development; learning outcomes; PjBL

Introduction

The current era is described as one of technological revolution, marked by rapid developments in digital technology and communication (Rohayati & Abdillah, 2024). These developments have expanded the use of computers and the internet in various aspects of life. Therefore, it is important to introduce technology into education and use it to develop learning processes aligned with the needs of the digital generation in the 21st century (Alshaikh, 2022). Similarly, technological developments also play a crucial role in improving chemistry education. Innovative learning is highly appropriate for use in chemistry teaching and learning to provide enjoyable learning, help students learn optimally, and make the teaching and learning process more effective and efficient (Afrinola et al., 2025).

Learning in analytical chemistry courses at the student level is divided into theory and practice, requiring a learning development process to align them (Yusfiani, 2020). One of the analytical chemistry topics crucial for chemistry students to understand is complexometric titration. Complexometric titration involves the formation of

complexes between the titrant and the analyte (Anasyah et al., 2025). The students still find complexometric titration difficult to understand. Liu et al. (2021) also noted that the selection of titration conditions, the effects of acidity, and complexometric titration curves are subtopics of complexometric titration that remain difficult for students to understand.

Based on observations of interviews conducted in the Chemistry Major of Universitas Negeri Medan, in teaching and learning activities, complexometric titration learning has not used learning media that can build student activity during learning, because learning is still quite focused on abstract theories through PowerPoint presentations that are dominated by verbal explanations, so that students gain more knowledge from the teacher's explanations than from finding out for themselves. The lack of overall student involvement in learning is due to insufficient student initiative to seek information independently. In addition, complexometric titration practicums were not conducted this semester due to insufficient time allocation for practicums since the block system was implemented. As a result, in terms of cognition, students' abilities remain low; the average learning

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achievement in the previous year was below the minimum competency standard, with around 16% of students having unsatisfactory learning outcomes.

Given these problems, active learning activities are needed to foster student engagement through Project-based Learning (PjBL). By using this learning strategy, the series of learning activities is not limited to listening, taking notes, and then memorizing the subject matter; students actively think, discuss, find solutions, process data, and present the results (Amaliya & Kubro, 2025). The project in this research is to introduce students to the developed virtual laboratory learning media. One effort that can be made to overcome the failure to conduct titration practicums due to time constraints is by utilizing computer application programs (courseware) in the form of virtual laboratories, which are currently widely available, either in the form of ready-made packages on compact discs or by downloading from the internet (Setiadi & Muflika, 2012).

In education, combining virtual learning with a project-based approach creates a creative method that supports independent learning. The results of research conducted by Situmorang et al. (2024) show that the use of innovative virtual laboratories that integrate project-based learning is very effective in improving student learning outcomes and higher-order thinking skills. This is also reinforced by Purwaningsih et al. (2024), who show that the development of virtual-laboratory-based modules combined with project-based learning is feasible and effective. Quantitatively, the pretest and posttest results show an increase in students' conceptual understanding, with an N-Gain of 0.55 (moderate category).

A virtual laboratory facilitates students' visualization of the submicro world, thereby creating a more supportive learning environment (Ali et al., 2022). The advantages of virtual laboratories are that the learning process becomes more interesting and interactive, teaching time can be reduced, the quality of learning can be improved, and teaching and learning can be carried out anywhere, anytime (Nirwana, 2016). One of the virtual laboratories developed by the researcher is the complexometric titration laboratory. The development of virtual laboratories was supported by PowerPoint, iSpring Suite 11, and Website 2 Apk Builder. Researchers used PowerPoint to create interactive multimedia learning materials. iSpring Suite is an application that is integrated with PowerPoint. Handayani & Rahayu (2020) stated that iSpring is a tool for designing and creating interactive learning media. iSpring can convert PowerPoint files to HTML5, allowing them to be used directly or optimized for e-learning. Website 2 Apk Builder is an application that can convert local HTML files published from iSpring Suite and Web URLs into an offline Android application.

Previously, Cuadros et al. (2015) reported on complexometric titration learning media, stating that iridium chemistry laboratory learning media could actively engage students in 2D (two-dimensional) learning. The researcher in this case developed a learning media laboratory with a more attractive, realistic graphical display and interactive features, and then modified it into an application to enhance active learning. The virtual complexometric titration laboratory is believed to be an effective learning medium in providing users with an analytical chemistry learning experience. Based on the identified problems, this study aims to determine the effectiveness of a virtual laboratory developed as part of a project to teach complexometric titration and improve student learning outcomes.

Methods

This study was conducted at the Department of Chemistry, Faculty of Mathematics and Natural Sciences, Medan State University. The population in this study consisted of all students majoring in chemistry in the 2023 chemistry education study program, comprising five classes at Medan State University. The sample was selected using random sampling, in which class PSPK 23D was the experimental class (using project-based learning with a virtual laboratory) and class PSPK 23A was the control class (using university learning media), as shown in Table 1.

Table 1. Two-group pretest-posttest research design

Group	Pretest	Treatment	Posttest
Experimental	O ₁	X ₁	O ₂
Control	O ₁	X ₂	O ₂

(Sugiyono, 2021)

Description:

- O₁: Before being treated, the experimental and control classes underwent an initial ability test (pre-test)
- O₂: Final ability test (post-test) in the experimental and control classes after being given treatment
- X₁: Treatment using the developed virtual laboratory media on complexometric titration
- X₂: Treatment using the conventional learning on complexometric titration

Student participation in this study was previously approved by each student, in accordance with the code of ethics for social science research applicable at the State University of Medan. This research is classified as Research and Development (R&D) using the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) to develop a virtual laboratory with projects for teaching complexometric titration. The virtual laboratory contains learning instructions, concept

maps, materials, videos, projects (simulations), evaluations, and developer profiles.

Research and development methods are used to produce new products or improve existing ones, enhancing effectiveness through a validation process and enabling scientific justification (Rustamana et al., 2024). This research was conducted in several stages, namely (1) developing a virtual laboratory with a project, (2) standardizing the virtual laboratory with the project developed using a BSNP standard questionnaire by validators, namely analytical chemistry lecturers, and (3) implementing the virtual laboratory with the developed project to students to determine the improvement in learning outcomes from this learning medium. Each validator standardized the media using the BSNP questionnaire, with assessment criteria including content feasibility, language, presentation, and graphics.

Before learning begins, students are given a multiple-choice test (pre-test) to determine their initial abilities. After learning is complete, students are given the same test again (post-test) to see changes or improvements in their learning outcomes. To demonstrate the improvement in student learning outcomes following the use of the virtual laboratory on complexometric titration, the N-Gain test was administered.

In this study, the data were analyzed using SPSS version 26.0 with the Mann-Whitney U test to determine whether there was a difference in the average results between the experimental and control classes. After conducting the test, students' responses regarding the development of a virtual laboratory for a project on teaching complexometric titration can be measured by distributing a student response questionnaire containing 10 statements.

Results and Discussion

This study aims to develop a virtual laboratory project on complexometric titration to improve student learning outcomes. This study is a Research and Development study using the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). In the initial stage, the researcher conducted a needs analysis through interviews and a literature review. In this R&D study, the needs analysis stage was intended to identify problems experienced by students and teachers during the learning process, so that the development of media/products could be appropriately targeted (Tani et al., 2023). Based on the interview results, it was found that in teaching and learning activities, complexometric titration is often taught using PowerPoint, which is designed to convey knowledge through lectures, question and answer sessions, and occasionally showing practical videos on YouTube so that students gain more knowledge from the teacher's explanations than from finding out for themselves. Students find complexometric titration difficult to understand. As

a result, in terms of cognitive skills, it is also lacking; the average learning achievement in the previous year remained below the minimum competency standard, with approximately 16% of students achieving less-than-satisfactory learning outcomes. Liu et al. (2021) and Fu et al. (2024) also noted that the selection of titration conditions, the effects of acidity, and complexometric titration curves are subtopics of complexometric titration that remain difficult for students to understand.

The second stage is to design virtual laboratory learning media, with projects ranging from product design to the collection of teaching materials and the design of mini-projects. Projects in virtual laboratories can facilitate independent learning for students (Sapriati et al., 2023). Overall, virtual laboratory media with projects effectively facilitate students' learning of basic analytical chemistry. Separating target compounds, calculating the products produced, and drawing conclusions from the project activities carried out (Li & Liang, 2024). This virtual laboratory media with projects consists of several menus: introduction, learning instructions, materials, learning videos, projects through virtual laboratory simulations, evaluations, and profiles.

Next is the development stage, which involves creating the learning media. The virtual laboratory was developed using PowerPoint, iSpring Suite 11, and Website 2 Apk Builder. This virtual laboratory media can be accessed on Android, on a PC (laptop), or via a website. This virtual complexometric titration laboratory is very practical and easy to use in understanding the concept of quantitative analysis through the topic of complexometric titration. The general appearance of the virtual complexometric titration laboratory is shown in Figure 1.



Figure 1. Virtual laboratory display of complexometric titration with projects: (a) virtual laboratory front page, (b) content, (c) complexometric titration experiment simulation, and (d) evaluation

Expert validators will then standardize virtual laboratory media with developed projects. Each validator standardizes the media using a BSNP feasibility questionnaire that assesses the feasibility of content, language, presentation, and graphics on a 1-4 Likert scale, as presented in Table 2.

Table 2. Standardization of virtual laboratory media with projects on complexometric titration teaching

No.	Aspect	Respondents' Opinion	Category
1.	Content Feasibility	86.67%	Very Good
2.	Language Feasibility	85.56%	Very Good
3.	Presentation Feasibility	87.50%	Very Good
4.	Graphical Feasibility	89.17%	Very Good
Average		87.06%	Very Good

Table 2 shows the results of the virtual laboratory media analysis with projects based on the BSNP questionnaire have the following averages: (1) content feasibility test of 86.67% (very good/very feasible); (2) language feasibility test of 85.56% (very good/very feasible); (3) presentation feasibility test of 87.50% (very good/very feasible); and (4) graphics feasibility test of 89.617% (very good/very feasible). Therefore, based on the BSNP feasibility results, the virtual laboratory media with projects obtained an average score of 87.06%, and was declared very good and very feasible for use as learning media on the topic of complexometric titration.

Based on the results of the validation of virtual laboratory media conducted by Nasution et al. (2023) it was proven that the virtual laboratory media was deemed very suitable for use in the learning process based on expert validation assessments in the language aspect of 90%, the display aspect of 87.02%, and the benefit aspect of 83.58%. This research is supported by Arini et al. (2021) and Nisa et al. (2023), who stated that virtual lab media can serve as a solution for chemistry materials that are difficult to visualize in real life, as they have been shown to improve understanding of abstract concepts and are practical for learning.

Expert validators have successfully standardized the virtual laboratory, and researchers then assessed student learning outcomes in complexometric titration teaching. Evaluation tests were conducted at the beginning and end of the session (pretest and posttest) to determine the mastery of complexometric titration concepts. Student learning outcomes were assessed using an objective test comprising 10 multiple-choice questions, each with 5 answer choices. Student learning outcome data from the experimental and control classes, obtained through pretest and posttest, are summarized in **Table 3**.

Table 3. Student learning outcomes based on pretest-posttest

Class	Learning Outcomes		N-gain Score	% N-gain
	Pretest	Posttest		
Experimental	35.28	78.89	0.68	68%
Control	33.61	72.50	0.59	59%

Based on **Table 3**, the experimental class obtained higher results than the control class, with pretest average scores of 33.61 ± 7.98 and 35.28 ± 8.78 , respectively. Meanwhile, the average posttest

score of the control class was 72.50 ± 8.06 , lower than that of the experimental class (78.89 ± 10.08). Students who achieved learning outcomes >75 were classified as competent (Sutiani et al., 2021). This research, supported by Munthe et al. (2024), shows that the posttest results for the control group ($M=61.7$) and the experimental group ($M=85.8$) indicate that learning outcomes are higher when students integrate learning package content with virtual laboratories. A similar finding was also reported by Bazie et al. (2024).

The results of this study are also reinforced by the research of Safitri & Kurniawati (2025), which shows that the virtual component in virtual labs has the potential to accelerate the improvement of chemistry concepts with an N-Gain increase of 0.77 in the high category in the experimental class while also increasing student engagement in project tasks with a student resonance score of 81.41%, which is categorized as very good. Therefore, the N-gain test results in this study indicate a difference in learning outcome improvement between the experimental and control classes. The improvement in learning outcomes in the experimental group ($M=0.68$) was greater than that in the control group ($M=0.59$). Based on the N-gain percentage of 56-75, which is categorized as effective, it can be concluded that the development of a virtual laboratory with projects for complexometric titration learning is effective.

After obtaining learning outcomes from pretest and posttest scores, a hypothesis test was conducted to determine whether virtual laboratories with projects were more effective than conventional teaching in improving student learning outcomes in complexometric titration, based on N-Gain scores for each class. For hypothesis testing, data requirements were first conducted, namely normality and homogeneity tests at a significance level of 0.05. The results of the normality test are shown in **Table 4**.

Table 4. Normality test of learning outcomes data

Group	Sig.	α	Category
Experimental	.001	0.05	Abnormal
Control	.084	0.05	Normal

Table 4 shows that the Sig. for the N-Gain score of the experimental class was $0.001 < \alpha < 0.05$; it can be concluded that the N-Gain score of the experimental class was not normally distributed (Putri & Alyani, 2023), while the N-Gain score of the control class was normally distributed ($0.084 < \alpha = 0.05$). The next was the homogeneity test of learning outcomes, as shown in **Table 5**.

Table 5. Homogeneity test of learning outcomes data

Group	Sig.	α	Category
Experimental	.005	0.05	Not homogeneous
Control		0.05	

The interpretation of the data in **Table 5** shows that the Sig value is $< \alpha = 0.05$; it can be seen

that the N-Gain for the experimental and control classes has different variants (not homogeneous). Since the assumptions of the normality test were not met and the data variance was not homogeneous, the hypothesis test used in this study was non-parametric: the Mann-Whitney U test, conducted at a 95% confidence level in SPSS 26 for Windows. The results of the Mann-Whitney U test are presented in **Table 6**.

Table 6. Mann-Whitney test of learning outcomes in experimental and control classes

	Learning Outcomes
Mann-Whitney U	428.000
Wilcoxon W	1094.000
Z	-2.599
Asymp.Sig. (2-tailed)	.009

Based on the Mann-Whitney U test results above, a sig. A value < 0.05 was obtained, so H_a was accepted: the learning outcomes of students taught using a virtual laboratory with projects in complexometric titration were higher than those of students not taught using one.

This is in line with research by Yanti et al. (2020) and Navarro et al. (2024), which indicates that learning with virtual laboratories improves student learning outcomes compared to learning with learning aids. In addition, learning with virtual laboratories can make students more engaged because they can conduct experiments directly. This is supported by research by Ariyanto et al. (2022), which states that the use of virtual laboratory media can help students understand concepts and improve active learning and learning outcomes. Learning videos and mini-project simulations integrated into virtual laboratories with projects can facilitate independent learning among students, thereby increasing their enthusiasm (Tsirulnikov et al., 2023). Therefore, it is concluded that the development of virtual laboratories with projects is effective in improving student learning outcomes in complexometric titration instruction.

After the learning process, student response questionnaires were distributed in the virtual laboratory, with projects carried out in the experimental class to assess the influence of the developed virtual laboratory on students' activity and enthusiasm, which will also affect student learning outcomes. Data on student responses to the virtual laboratory are shown in **Table 7**.

Table 7. Result of student response to the virtual laboratory

No.	Aspect	Respondents' Opinion (%)	Category
1.	Challenge	81.3	Good
2.	Curiosity	91	Very Good
3.	Engagement	86.8	Very Good
4.	Confidence	83	Good
5.	Attention	93.1	Very Good
6.	Relevance	88.2	Very Good
7.	Satisfaction	90.3	Very Good
Average		87.65	Very Good

Based on **Table 7**, the average student response to the virtual laboratory is 87.65%, which

falls in the very good category. This study was supported by Berdi et al. (2025), who reported that students' perceptions of the virtual laboratory showed 65-80% positive responses on indicators such as satisfaction, ease of use, understanding, and practical readiness, thereby impacting learning outcomes, with an N-Gain value of 66%. These students are also very influential in the activity and enthusiasm of students using the virtual laboratory developed to improve student learning outcomes.

Conclusions

A virtual laboratory project for teaching complexometric titration in analytical chemistry has been successfully developed in accordance with the KKN curriculum. The virtual laboratory developed for the project effectively facilitates active learning to achieve competence in complexometric titration. The results of the feasibility validation by experts show that the virtual laboratory in the developed project has met BSNP requirements. Student learning outcomes from objective tests indicate that the N-Gain in the experimental class was significantly higher than that in the control class. At the same time, student response to a virtual laboratory project is in a very good category. Therefore, it is concluded that developing a virtual laboratory with projects is highly feasible for use in complexometric titration instruction to improve student learning outcomes.

Conflict of Interest

Regarding this study, the authors declare no financial or commercial conflicts of interest.

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