



Development and Implementation of a Virtual High Performance Liquid Chromatography (HPLC) Laboratory to Enhance Learning Outcomes in Analytical Chemistry

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Abstract: Development and Implementation of a Virtual High Performance Liquid Chromatography (HPLC) Laboratory to Enhance Learning Outcomes in Analytical Chemistry. In the implementation of High Performance Liquid Chromatography (HPLC) learning, in addition to understanding the material, students must conduct practical work to effectively understand the system and operation of HPLC instrumentation. However, due to the limitations of facilities and access to physical laboratories for HPLC instrumentation, an innovative learning resource, namely the Virtual HPLC Laboratory, has been developed. This study aims to determine the improvement in student learning outcomes and motivation through the use of Virtual High Performance Liquid Chromatography (HPLC) laboratory media in HPLC learning. This research was conducted in the Chemistry Department of Universitas Negeri Medan during the even semester of the 2025 academic year. This study employs a Research and Development (R&D) approach with a 4D (Four-D) development model. The research sample consists of class PSKM 23 B as the experimental group and class PSKM 23 A as the control group, which were selected through total/saturation sampling method. The implementation of the Virtual HPLC Laboratory developed in this study has several findings, namely The developed virtual laboratory is effective for use in learning, The developed Virtual HPLC Laboratory meets the modified criteria of the National Education Standards Agency (BSNP), The Virtual HPLC Laboratory effectively improves the learning outcomes of analytical chemistry separation, Through a two-sample t-test, it has been proven that there is an effect of using the Virtual HPLC Laboratory media on students' learning outcomes in teaching analytical chemistry separation, Through an independent sample t-test, it has been proven that there is a difference in students' learning outcomes who are taught using the Virtual HPLC Laboratory compared to those taught using student guide learning resources, and through the completion of a student learning motivation questionnaire, it can be concluded that the use of the Virtual HPLC Laboratory affects and enhances students' learning motivation in HPLC training.

Keywords: High Performance Liquid Chromatography, Virtual Laboratory, Learning Outcomes, Learning Motivation, and Analytical Chemistry Separation.

Abstrak: Pengembangan Dan Implementasi Laboratorium Virtual High Performance Liquid Chromatography (HPLC) Untuk Meningkatkan Hasil Belajar Kimia Analitik. Dalam pelaksanaan pembelajaran High Performance Liquid Chromatography (HPLC), Selain memahami materi, mahasiswa harus melakukan praktikum untuk memahami sistem dan cara kerja instrumentasi HPLC dengan baik. Namun dengan keterbatasan fasilitas dan akses laboratorium fisik untuk instrumentasi HPLC, maka dikembangkan inovasi sumber belajar yaitu Laboratorium Virtual HPLC. Penelitian ini bertujuan untuk mengetahui peningkatan hasil belajar dan motivasi siswa melalui penggunaan media laboratorium Virtual High Performance

Liquid Chromatography (HPLC) dalam pembelajaran HPLC. Penelitian ini dilaksanakan di Jurusan Kimia Universitas Negeri Medan selama semester genap tahun akademik 2025. Penelitian ini menggunakan pendekatan Penelitian dan Pengembangan (R&D) dengan model pengembangan 4D (Four-D). Sampel penelitian terdiri dari kelas PSKM 23 B sebagai kelompok eksperimen dan kelas PSKM 23 A sebagai kelompok kontrol, yang dipilih melalui metode sampling total/jenuh. Implementasi Laboratorium Virtual HPLC yang dikembangkan pada penelitian ini memiliki beberapa temuan, yaitu Laboratorium virtual yang dikembangkan efektif penggunaannya dalam pembelajaran, Laboratorium Virtual HPLC dikembangkan telah memenuhi kriteria Badan Standar Nasional Pendidikan (BSNP) yang dimodifikasi, Laboratorium Virtual HPLC efektif meningkatkan hasil belajar kimia analitik pemisahan, melalui uji two sample t-test dibuktikan bahwasanya terdapat pengaruh penggunaan media Laboratorium Virtual HPLC terhadap hasil belajar mahasiswa pada pengajaran kimia analitik pemisahan, melalui uji independent sample t-test dibuktikan bahwa terdapat perbedaan hasil belajar mahasiswa yang dibelajarkan menggunakan Laboratorium Virtual HPLC dengan hasil belajar mahasiswa yang dibelajarkan menggunakan sumber belajar pegangan mahasiswa, melalui pengisian angket motivasi belajar mahasiswa, dan dapat disimpulkan bahwa penggunaan Laboratorium Virtual HPLC mempengaruhi dan meningkatkan motivasi belajar mahasiswa pada pangaaran HPLC.

Kata kunci: *High Performance Liquid Chromatography, Laboratorium Virtual, Hasil Belajar, dan Motivasi Belajar, Kimia Analitik Pemisahan.*

■ INTRODUCTION

Virtual laboratories are interactive scientific situations simulated through computer applications and serve as simulations of scientific experiments. Virtual laboratories can be used to support the learning process, enhance students' understanding of the material, and predict the lack of preparation for actual practical work. According to Soni and Katkar (2014), virtual laboratories are interactive experiences where individuals view and manipulate objects, data, or phenomena created by the system to meet learning objectives (Hikmah et al., 2017). The development of information and communication technology has great potential in improving the quality of education. Experiments that are difficult to conduct in a physical laboratory and usually have minimal practical equipment can also be carried out using virtual laboratory media. Virtual media are interactive multimedia objects that have various formats, such as sound, images, animation, video, text, and graphics. (Dewa et al., 2020).

In learning Analytical Chemistry, students often encounter challenges, particularly in grasping the subject when laboratory practice is not included. This results in difficulties for many students in acquiring knowledge and skills in the analytical field. Such challenges can stem from unsystematic teaching methods, which hinder students' understanding of analytical concepts. Additionally, if the material is not presented in a contextual manner, students may struggle to comprehend accurate chemical concepts. Misconceptions further exacerbate the difficulties in learning analytical chemistry (Sari et al., 2020). Especially in the implementation of High Performance Liquid Chromatography (HPLC) learning, in addition to understanding the material, students must conduct practical work to understand the system and the working mechanism of HPLC instrumentation well. HPLC is one of the most important materials because it is widely used in the industry due to its advantages in both qualitative and quantitative analysis processes.

The term chromatography designates several similar techniques that allow the separation of different molecular species from a mixture. Applications of chromatography

are numerous, and can be related to laboratory or industrial practices. Analytical chromatography uses a chromatographic separation of the compound from a sample and for the identification and measurement of these compounds uses a specific detection (Moldoveanu & David, 2022). In studying HPLC material, students must understand the correct concepts and techniques, including the basic principles, chromatography parameters, and how to prepare samples for operation (Yulina et al., 2022). The implementation of virtual laboratories serves as a substitute for hands-on activities in potentially dangerous environments, such as actual chemistry labs. This approach utilizes computers to simplify complex concepts and provide alternatives to costly practical equipment and instruments. Virtual laboratory media represent a significant innovation in experimental learning methods, particularly in laboratory education, by offering a safer and more accessible platform for understanding intricate procedures and tools (Dewi et al., 2024).

In the digital era, the demand for innovative teaching materials is crucial, given that students often prefer learning methods aligned with the latest technological advancements. These materials aim to enhance the quality of education by optimizing teaching and learning processes to achieve desired learning outcomes. Moreover, innovative teaching resources support the shift from traditional learning approaches to a more student-centered learning environment, fostering greater engagement and autonomy (Martalina & Situmorang, 2018).

The constraints of traditional experiments can be addressed through virtual experiments, which provide an accessible alternative for all students. A virtual laboratory is a real practical exercise conducted through a computer and can be used to enhance education at the University. Considering the important role of educators in facing the challenges of the times, education practitioners must be prepared to face the 5.0 Industrial Era with the concept of self-directed learning. Educators' responsibilities must be demonstrated by a strong willingness to continue learning and adapting to changes in order to equip students with future skills and encourage lifelong learning. To tackle these challenges, high-quality and talented individuals are needed. Quality education plays a very important and strategic role in developing quality human resources (Lestiyani, 2020). The importance of using virtual laboratories as an innovative learning tool in high-performance liquid chromatography materials is expected to improve students' learning outcomes and understanding in high-performance liquid chromatography studies. Additionally, with the presence of virtual laboratories, students can understand the concepts of high-performance liquid chromatography practically by conducting virtual experiments, where hands-on experiments in a real laboratory cannot be executed due to insufficient laboratory facilities.

■ **METHOD**

This study was conducted at Medan State University, located at Jl. William Iskandar Pasar V, Percut Sei Tuan District, Deli Serdang Regency, North Sumatra, from October 2024 to May 2025, during the even semester of the 2025 academic year. The population comprised all students from the Chemistry Study Program, 2023 cohort, enrolled in the separation chemistry course during this period, distributed across two classes. The sample was selected using a saturated or total sampling technique, which involves utilizing the entire population as the sample. As noted by Al Mawaddah et al. (2021), this method is characterized by including all members of the population in the sample. This study employed a Research and Development (R&D) approach, utilizing

the 4D (Four D) development model. The model encompasses four primary stages: Define, Design, Develop, and Disseminate. The 4D model was first developed by Thiagarajan, Semmel, and Semmel (1974), driven by the need for an instructional development model that could ensure the quality and applicability of products in the learning context (Alghiffari et al., 2024). This approach has since proven to be relevant and flexible for use in various educational contexts, including in Indonesia.

Research Design

This study employed a Pretest-Posttest Control Group Design, which is represented in **Table 1**.

Table 1. Research Design

Ekspersimen Class	T ₁	X	T ₃
Control Class	T ₂		T ₄

(Source: Silitonga, 2013)

This study used an experimental class that was taught using the HPLC Virtual Laboratory and a control class that was taught using student handbook learning resources. Both classes underwent pretest-posttest to analyze learning outcomes, as well as to determine the comparison of learning resources that influenced the outcomes through statistical analysis. This research model is a Pretest-Posttest Control Group Design, which can be seen in the **Table 1**.

Research Procedures

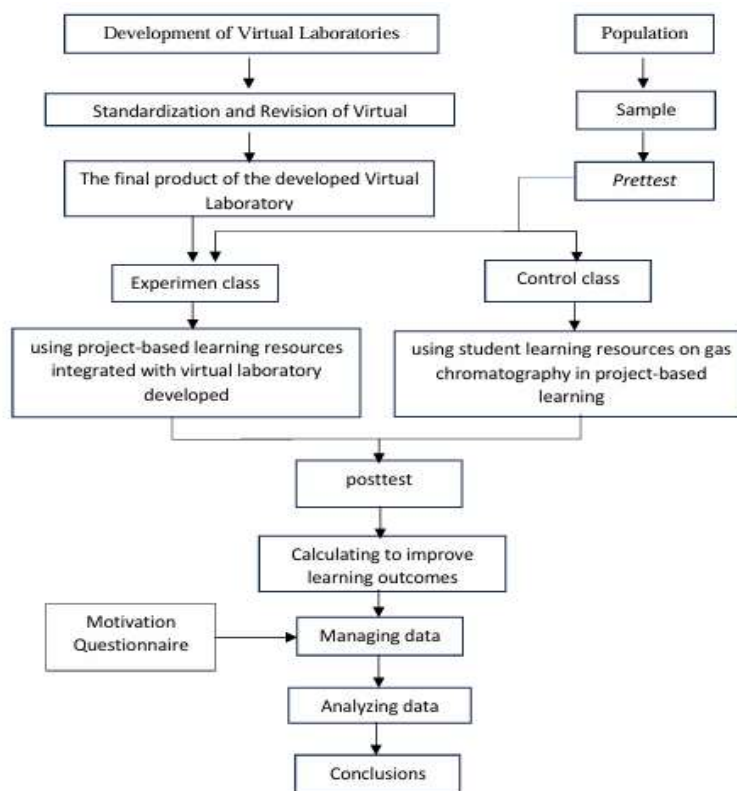


Figure 1. Research Prosedure Flowchart

■ **RESULT AND DISCUSSION**

RESULT

This study aims to develop a Virtual Laboratory on High Performance Liquid Chromatography (HPLC) material to improve students' analytical chemistry learning outcomes and facilitate practical learning, particularly in the Separation Chemistry course. The development of this virtual laboratory is carried out using the 4D development model approach, which includes the stages of Define, Design, Develop, and Disseminate. The initial stage of this research is the validation of the test instruments. The HPLC test instrument to be validated consists of 40 multiple-choice questions, which will be trialed on 30 students who are the subjects of the analysis. Validity is measured using the product moment correlation. From the validation conducted, the following results were obtained:

1) Validity Tes

The criteria used for validity testing are that if the correlation coefficient (r result) is greater than the critical value (r table), r result $>$ r table, then the test item is considered valid.

Table 2 validity test results on the HPLC test instrument

Category	Number of Question											Items Total	
Valid	2	3	4	5	8	9	11	12	13	14	15	32	
	16	17	18	19	20	21	22	24	25	26	27		
	28	29	30	31	32	34	35	36	37	39			
Invalid	1	6	7	10	23	33	38	40					8

In **Table 2**, with a sample size of $N=30$ at a significance level of $\alpha = 0.05$, the obtained r -table value is 0.361. The calculation results show that 32 test items are considered valid, while 8 test items are invalid.

2) Level of difficulty

The analysis of test difficulty levels is conducted to determine whether a test is classified as easy ($P = 0.81-1.00$), moderate ($P = 0.21-0.80$), or difficult ($P = 0.00-0.20$). A test item is considered appropriate if the P value is within the range of 0.20-0.80. Items with $P < 0.20$ are considered too difficult, whereas $P > 0.80$ is considered too easy. Based on the analysis results, out of 40 tested questions, there are 7 questions in the easy category, 33 questions 28 in the moderate category, and no questions in the difficult category. Based on the acceptance criteria for a good test difficulty level, it is known that out of 40 questions, 7 questions do not meet the requirements for a good difficulty level.

3) Differentiating Power

The test Differentiating index (D) indicates an item's ability to differentiate between students with high and low abilities. An item is considered adequate if the D value is in the range of +0.2 to +1.0. Based on the Differentiating index calculation results, out of 40 analyzed questions, 23 questions meet the adequate discrimination criteria, while 17 questions do not meet these criteria.

4) Reliability Test

In this study, the reliability of the test items was tested using the Kuder Richardson 20 (KR-20) method, which yielded a calculated value (r) of 0.89952. This value was

compared with the table value (r table) of 0.361. Since the calculated r (0.89952) is greater than the table r (0.361), it can be concluded that the criteria for item reliability are met. Thus, all 22 items used in this study have a high level of reliability.

Virtual HPLC Laboratory for HPLC Teaching

The outcome of this research is a Virtual Laboratory specifically developed for the High-Performance Liquid Chromatography (HPLC) topic, designed for Chemistry Department students at Universitas Negeri Medan enrolled in the Separation Chemistry course. The research design followed four primary stages: Define, Design, Develop, and Disseminate.

Results of the Needs Analysis

The initial stage before starting the development of the Virtual HPLC Laboratory involves first conducting a needs analysis of students' learning resources regarding HPLC teaching, measured using a questionnaire distributed to classes that have taken the Separation Chemistry course in the previous semester. This study uses subjects that consist of 30 chemistry major students from the FMIPA, Universitas Negeri Medan. The results of the needs analysis indicate that there is still limited access to physical laboratories for HPLC instrumentation, thus requiring an innovation of a more flexible Virtual HPLC Laboratory. After conducting the initial needs analysis, the development of the Virtual HPLC Laboratory was carried out using the 4D development model and standardized according to the modified BSNP feasibility criteria.

Define

Through the initial analysis, it was found that there were no practical/theoretical experiments conducted in the learning of the HPLC material in the Separation Chemistry course. As an alternative to this issue, the proposed solution is to develop a specific software in the form of a Virtual Laboratory for HPLC material that can be accessed via PC or Android. This can help enhance students' abilities through the theory presented and simulations conducted within the developed Virtual Laboratory for HPLC.

In this case, the analysis of the main tasks that students must master is that students can integrate basic and additional skills to be able to compile a quality project report that has been assigned in the Virtual HPLC Laboratory, in accordance with the minimum competencies set in the curriculum. This is to ensure that students can achieve the minimum competencies established through the student project report assessment. In the concept analysis, the main concept that will be taught is the material on High Performance Liquid Chromatography (HPLC) that focuses on Reverse Phase HPLC (RP-HPLC) type.

Based on the analysis of the curriculum and problem identification, specific learning objectives have been formulated. The Learning Objectives using the Virtual HPLC Laboratory in this research are: (1) Through the Virtual HPLC Laboratory simulation, students are able to explain the basic principles of HPLC, the main components of the instrument, and the function of each component in the HPLC system. (2) Through the Virtual HPLC Laboratory, students are able to utilize the virtual laboratory media to independently train their laboratory skills, improve efficiency, and enrich their learning experience.

Design

The second stage in this research is to design a Virtual HPLC Laboratory, resulting in a prototype (initial design) for the content of High Performance Liquid Chromatography (HPLC). The activities at this stage involve defining and designing, which includes the formulation of test standards based on the analysis of learning objectives and the characteristics of the learners. Additionally, the selection of media must be based on the results of concept analysis, task analysis, the characteristics of students as users, and dissemination plans with various types of media. Therefore, Virtual Laboratory media is used and developed using High Performance Liquid Chromatography (HPLC) content. The initial design of this research is a virtual laboratory featuring High Performance Liquid Chromatography (HPLC) content. The Virtual Laboratory HPLC Software consists of a Login Page, Main Menu, Learning Objectives and Course Learning Outcomes (CPMK), Introduction to HPLC, HPLC Material, Work Procedures, Simulation, and Peak Report.

Develop

The results of the Virtual HPLC Laboratory media development show that the 4D model approach is effective in producing interactive, relevant, and needs-oriented learning media for HPLC studies. The stages of creating the Virtual High Performance Liquid Chromatography (HPLC) Laboratory include inputting the predetermined content from the initial design into the virtual laboratory using the Construct 3 application. The design of the virtual laboratory is presented in a 2D format.

The Virtual HPLC Laboratory is equipped with Learning Objectives and CPMK, Introduction to High Performance Liquid Chromatography (HPLC), HPLC Materials, Practical Work Procedures, and HPLC Simulations. The components of the HPLC Laboratory include the Login Page, Main Menu, Learning Objectives and Course Learning Outcomes (CPMK), Introduction to HPLC, HPLC Materials, Work Procedures, Simulations, and Peak Report.




Disseminate



The products that have been revised during the development stage are applied to the actual target or objective, namely in the experimental class (PSKM 23 B). The goal of measuring the achievement of objectives in the test validation stage is to determine how effective the product created is through the pretest and posttest that have been conducted previously. Furthermore, after implementation, the researcher also distributed a questionnaire on student motivation towards the Separation Chemistry learning using Virtual Laboratory HPLC.

Development of Virtual HPLC Laboratory

The development of the Virtual HPLC Laboratory was organized using the 4D development model, as discussed in the previous chapter. This research resulted in a product in the form of a Virtual Laboratory on HPLC materials for teaching Analytical Chemistry Separation. The results of the development of the Virtual HPLC Laboratory are described in **Table 3**.

Tabel 3. Description of the Virtual HPLC Laboratory for Teaching Analytical Separation Chemistry

No	Sub Topic	Material Content	Description	Page
1	Learning Objectives and CPMK	This page lists the Learning Goals and CPMK.	Learning objectives are determined based on curriculum analysis and problem identification.	
2	Introduction to HPLC	This menu briefly describes HPLC instrumentation.	The innovation on this topic is to compare HPLC separation techniques with other separation instruments by demonstrating the advantages of HPLC.	
3	HPLC Material	This menu contains HPLC material that includes the working principles, developments in HPLC, basic components, HPLC maintenance, advantages and disadvantages, HPLC contributions in the modern era, as well as qualitative and quantitative analysis techniques in separation using HPLC.	The innovation carried out in this subtopic is to discuss the development of HPLC in detail and include images of HPLC instruments. This subtopic also discusses the contribution of HPLC in the modern era as well as the handling of HPLC waste.	

4	HPLC Simulation	This menu is the core of the Virtual HPLC Laboratory, which contains HPLC simulations with experiments for analyzing vitamin C levels.	The innovation in this subtopic is presented with an attractive display design, where this page features a depiction of the HPLC instrument and supporting laboratory tools for HPLC practicals in the form of animation. The adjustment of color appearance, animation design, and layout are arranged neatly to make the Virtual HPLC Laboratory visually more appealing, and the use of the Virtual HPLC Laboratory can be conducted anywhere, including outside the Chemistry Separation course hours. In this experiment, three types of vitamin C samples are used, where students are asked to analyze the concentration of vitamin C in each sample obtained from the HPLC chromatogram.	
5	HPLC Evaluation	This menu contains HPLC test instruments that are directly connected to Google Forms.	The innovation in this menu is the HPLC test instrument arranged based on Bloom's taxonomy (C2-C6) that has been validated.	

The developed Virtual HPLC Laboratory has innovations from the previously used learning resources, namely digital-based learning resources that can be downloaded in the form of an application or accessed via a link (to avoid issues with internal storage). The developed Virtual HPLC Laboratory also has advantages in the HPLC material that can be downloaded in the form of PowerPoint files so that students can study it without internet access. The simulation used in this Virtual HPLC Laboratory is 'Vitamin C Concentration Analysis', where the simulation uses three different types of samples distinguished by the color choices of the vitamin C sample. The HPLC simulation includes an assignment in the form of a project report, where in this assignment students

are guided to prepare a practical report and explain qualitative and quantitative analysis techniques on the HPLC chromatograms for each sample.

Learning Activities using the HPLC Virtual Laboratory

The Virtual HPLC Laboratory in the form of an application that can be downloaded on PC or Android and all learning devices was tested at the research location, namely class PSKM 23 A as the experimental class in the Department of Chemistry at Universitas Negeri Medan with a total of 34 students. This study also used a control class (PSKM 23 B) with a total of 36 students, who used general learning resources provided by the Chemistry Separation lecturer in class PSKM 23 A. Thus, the total subjects in this study are 70 students. The experimental class used SIPDA to access the Virtual HPLC Laboratory link and tasks. **Figure 2** displays the SIPDA of the experimental class.

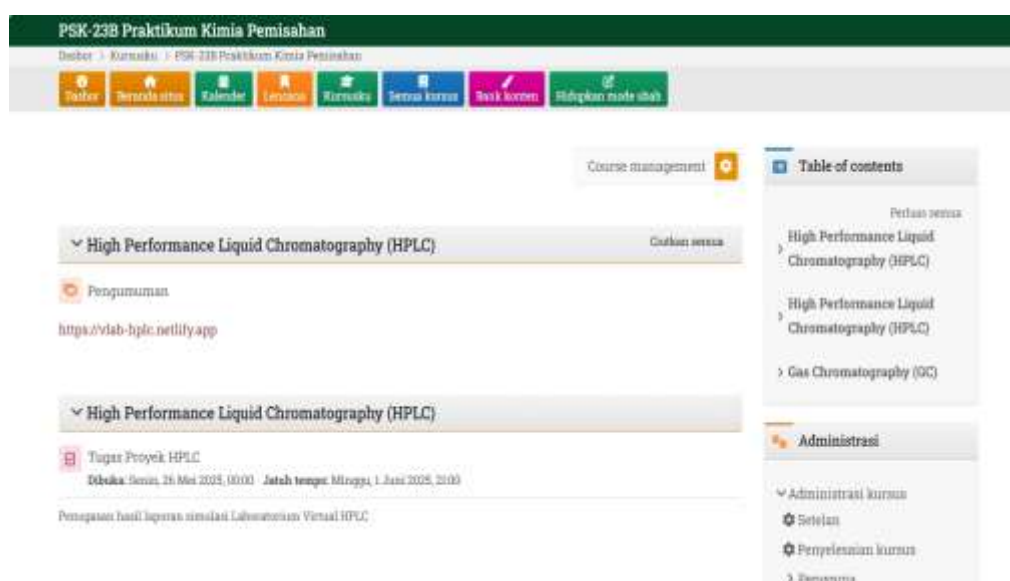


Figure 2. SIPDA display experimental class

From **Figure 2**, the components of the learning device are visible, namely the Virtual HPLC Laboratory and project assignment submission, where a time limit for submission is given. Before conducting the practical work, each class group is given a pretest. Next, the experimental group is asked to study the learning resource of the Virtual HPLC Laboratory, which contains HPLC materials that can be downloaded in the form of PowerPoint (PPT) slides.

The next stage is for students in their respective groups to carry out HPLC simulations in the developed Virtual HPLC Laboratory and create practical reports in the format determined by the researcher. Meanwhile, for the control class, after studying the separation chemistry in relation to HPLC with the lecturer in charge of Separation Chemistry in class PSKM 23 A.

After the lessons in both classes were completed, a post-test was conducted aimed at assessing the improvement in learning outcomes. After that, the students from the experimental class were asked to fill out a motivation questionnaire regarding the use of the Virtual HPLC Laboratory. The motivation questionnaire was filled out by 34 students from the experimental class, distributed by the researcher and collected from each student through a Google Drive link. The table of research results on teaching and learning activities can be found in the **Table 4**.

Table 4 Description of student activities in the implementation of HPLC-based virtual laboratory learning.

No	Student Activities	Activity Description	Research Results
1	Downloading the Virtual HPLC Laboratory	Students access the download link for the Virtual HPLC Laboratory through SIPDA. (Figure 2) http://vlab-hplc.netlify.app	All students have the HPLC Virtual Laboratory application.
2	Students access the Virtual HPLC Laboratory in menu 1, menu 2, and menu 3.	Students use the virtual HPLC laboratory <ul style="list-style-type: none"> ● CPMK and TP ● Introduction to HPLC ● HPLC Material (HPLC Instrumentation, Development of HPLC, Basic Principles of Analysis using HPLC, and Qualitative and Quantitative Analysis in HPLC) 	Students understand the working principles of HPLC and the analytical techniques on HPLC in theory.
4	Students access the Virtual HPLC Laboratory in menu 4.	The students performed HPLC simulation in the Virtual Laboratory following the work procedures available in the simulation menu. After analyzing the vitamin C content in 3 samples, an HPLC chromatogram was obtained, which was then analyzed qualitatively and quantitatively.	Students in each group discussed the results of the observations obtained from the simulation.
5	Project report assignment	Students work on practical reports based on their respective groups. The report includes observations of the results from the HPLC simulation and calculates the concentration of Vitamin C in each sample.	Submission of project assignments by each student uploaded in SIPDA.

Table 4 shows the activities carried out by students in the experimental class during the integrated learning activities of the Virtual HPLC Laboratory, with assigned tasks that have been predetermined. With the right learning design, virtual laboratories can enhance learning activities and maximize student understanding.

Standardization of Virtual HPLC Laboratory

The validation activities were conducted by submitting the Assessment Instrument Questionnaire for the Feasibility of the Virtual High Performance Liquid Chromatography (HPLC) Laboratory Media based on the modified BSNP and providing the link to the HPLC Virtual Laboratory to the validators to facilitate the assessment of the media. Subsequently, the validators evaluated and provided feedback on what needed to be revised, and the researchers made revisions to the HPLC Virtual Laboratory media. The results of the standardization are summarized in **Table 5**.

Table 5. Tabulation of Virtual HPLC Laboratory Assessment Results

No	Assessment Aspect	Respondents Opinions (M±Sdv) (n=2)	Percentage (%)
1	Content Feasibility	3,22±0,50	80,55
2	Linguistics	3,60±0,45	90

No	Assessment Aspect	Respondents Opinions (M±Sdv) (n=2)	Percentage (%)
3	Depth of Material	3,50±0,35	87,50
4	Presentation and Graphic Design	3,72±0,26	93
	Average each aspect	3,51±0,39	87,76

Based on **Table 5**, a graph can be obtained that illustrates the average scores for each aspect assessed in the standardization of the developed Virtual HPLC Laboratory media. The graph is shown in **Figure 3**

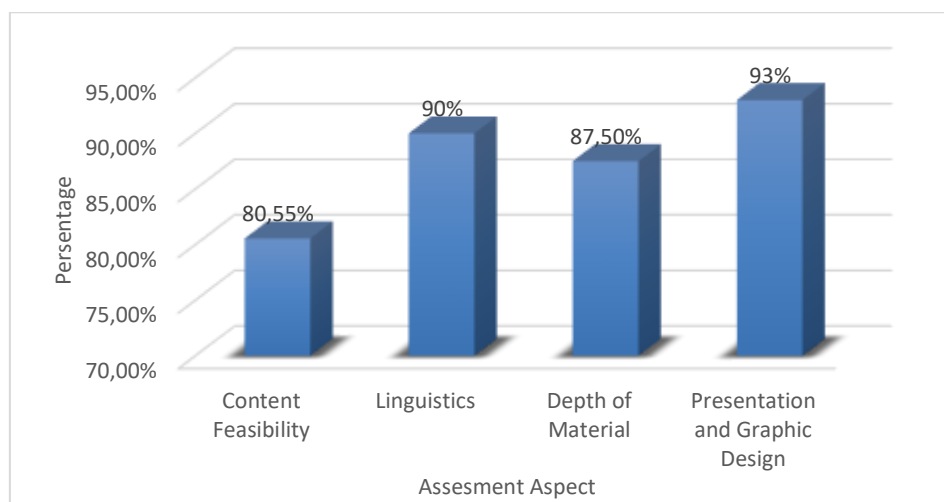


Figure 3. Persentase Aspek Penilaian Laboratorium Virtual HPLC

Based on the assessment of the Virtual HPLC Laboratory in Table 5 and the graph in Figure 3 above, it is obtained that the average media validation from the developed Virtual HPLC Laboratory is 3.51055 with a standard deviation of 0.39517 and a percentage of 87.76% in the category of 'Very feasible'. The aspect that produces the highest average percentage is in the aspect of Presentation and Graphics with a Percentage of 93% (3.72; 0.2635).

Implementation of Virtual Laboratory in HPLC Teaching

In this HPLC learning, it uses the Course Learning Outcomes (CLO) "Students have knowledge and skills in qualitative and quantitative analysis in High Performance Liquid Chromatography (HPLC) instrument for Vitamin C sample analysis." The learning objectives set by the researcher include: Theoretical basis of HPLC (Description of HPLC, development of HPLC, basic components, working principles, advantages and disadvantages, and HPLC for other fields), waste management from HPLC usage, maintenance of HPLC, and analysis of chromatogram results both qualitatively and quantitatively.

Learning Activities Using HPLC Virtual Laboratory

The use of RPM makes the learning process more systematic and effective with the time allocated for each stage. A summary of students' learning activities is shown in **Table 6**.

Table 6. Summary of Learning Activities Using Virtual HPLC Laboratory

No	Student Activity	Activity Description
1	Downloading the Virtual HPLC Laboratory	Students access the download link for the HPLC Virtual Laboratory through SIPDA (Figure 2)
2	Measuring the initial abilities of students	The students are taking the pretest that was distributed to measure their initial abilities.
3	Studying HPLC using a Virtual Laboratory	Students use the virtual HPLC laboratory <ul style="list-style-type: none"> ● CPMK and TP ● Introduction to HPLC ● HPLC Material (HPLC Instrumentation, HPLC Development, Basic Principles of Analysis using HPLC, and Qualitative and Quantitative Analysis in HPLC)
4	HPLC Simulation	The students performed HPLC simulation in the Virtual Laboratory following the work procedures available in the simulation menu. After analyzing the vitamin C content in 3 samples, an HPLC chromatogram was obtained, which was then analyzed qualitatively and quantitatively.
5	Project report assignment	Students work on practical reports based on their respective groups. The report includes observations of the results from the HPLC simulation and calculates the concentration of Vitamin C in each sample.
6	Evaluation	Students access the fifth menu in the Virtual HPLC Laboratory, which is the evaluation menu to measure students' learning outcomes.
7	Filling out the learning motivation questionnaire	Students fill out a learning motivation questionnaire and submit it via Google Drive.

Learning activities in the experimental class are conducted using the Project-Based Learning (PjBL) model, where the project assignment consists of a practical report prepared by students and submitted through the SIPDA task submission.

The Influence of Virtual HPLC Laboratory on Improving Learning Outcomes

Data analysis is carried out to process and interpret the data obtained from the research, resulting in information that is valid, relevant, and can be used to address the research problem formulation or test hypotheses. From the results of the pretest-posttest, a normality test is conducted to determine whether the research data follow a normal distribution. The Chi-Square Test (X^2) is used to test the normality of the obtained data. The calculated chi-square value (X^2) is compared with the Chi-Square Table value at $\alpha = 0.05$ with $df = 5$. If $X^2 < \text{Chi-Square Table value}$, then the data are normally distributed (Silitonga, 2014). The normality data of the pretest-posttest are presented in the **Table 7**.

Table 7. Analysis of Normality Test Data of Learning Outcomes

Kelas	Chi Kuadrat Hitung		Sig (0,05)
	Prettest	Posttest	
Eksperimen	6,1818	3,0909	11,07
Kontrol	7,2166	2,8333	11,07

From the normality test conducted on the Pretest scores of students in the experimental class, a calculated F value of 6.1818 and an F table value (Sig 0.05) of 11.07 were obtained. The value obtained from F calculated $<$ F table (Sig 0.05), meaning the

pretest data in the experimental class is normal. For the normality test on the Pretest data for the control class, a calculated F value of 7.2166 and an F table value (Sig 0.05) of 11.07 were obtained. The value obtained from F calculated < F table (Sig 0.05), meaning the pretest data in the control class is normal. Then, in **Table 7**, it can also be seen that for the Posttest data in the experimental class, a calculated F value of 3.0909 and an F table value (Sig 0.05) of 11.07 were obtained. The value obtained from F calculated < F table (Sig 0.05), meaning the posttest data in the experimental class is normal. For the normality test on the posttest data for the control class, a calculated F value of 2.8333 and an F table value (Sig 0.05) of 11.07 were obtained. The value obtained from F calculated < F table (Sig 0.05), meaning that the posttest data in the control class are normal. A homogeneity test was conducted on the pretest and posttest data to determine whether the data were homogeneous or not. The results of the homogeneity test for the Experimental and Control classes are presented in the **Table 8**.

Table 8. Analysis of Homogeneity Test Data of Learning Outcomes

Data	F hitung	F tabel (0,05)
Prettest	1,6078	1,8
Posttest	0,3222	1,8

Based on the analyzed research data, information was obtained regarding the average pretest, posttest, and n-Gain values as shown in **Table 9**.

Table 9. Average Pretest-Posttest Scores of Students.

Class	N-Gain	Learning Outcomes (M ± Sdv)	
		Pretest	Posttest
Experimen	0,7671	30,4756 ± 11,1623	84,6191 ± 7,3954
Control	0,1146	43,3042 ± 8,8029	51,3858 ± 13,0272

N-Gain data shows a difference in learning outcome improvement between the experimental class, which reached 76.71%, and the control class, which reached 11.46%. This variance is caused by differences in the learning approaches implemented between the experimental and control classes in the context of High Performance Liquid Chromatography (HPLC) learning, where the control class uses student handbook learning resources, while the experimental class learning takes place using virtual laboratory learning resources.

Hypothesis Test

The Two Sample t-test is used to assess the effect of learning using Virtual HPLC Laboratory on the improvement of learning outcomes in Analytical Chemistry Separation. The results of the Two Sample t-test analysis can be seen in **Table 10** below:

Table 10. Two Sample t-test on the first Hypothesis

	Mean	sig (two tailed)	t hitung	t tabel
Prettest	30,4352	0,0000	2,0369	1,6900
Posttest	84,7042			

From the **table 10**, it can be seen that the Sig. (2-tailed) value is 0.000, which is less than 0.05. This indicates that the null hypothesis (H0) is rejected and the alternative hypothesis (Ha) is accepted. The Two Sample t-test also resulted in a calculated t of 2.0369, which is greater than the t table (1.6900), thus it can be concluded that learning using the Virtual HPLC Laboratory has an effect on improving the results of learning Analytical Chemistry Separation.

Analysis using the Independent Sample T-test was conducted to determine whether the hypothesis is accepted or rejected. The test was carried out between the control class and the experimental class to find out whether there is a significant difference in student learning outcomes between the learning method using the Virtual Laboratory and the conventional learning method. The data tabulation from the hypothesis testing can be seen in **Table 11**.

Table 11. of the Independent Sample T-test on the second hypothesis

	Mean	sig (two tailed)	t hitung	t tabel
Experimen	84,6191	0,0000	1,9955	1,6900
Control	51,3858			

From the **table 11**, it is evident that the Sig. (2-tailed) value is 0.000, which is less than 0.05. This indicates that the null hypothesis (H0) is rejected and the alternative hypothesis (Ha) is accepted. From the processed data, the calculated t value is also obtained at 1.9955, which is greater than the t table (1.6900), thus it can be concluded that there is a significant difference in student learning outcomes between the use of Virtual Laboratory and conventional learning methods.

Motivation to Learn Using Virtual HPLC Laboratory

After the experimental class students underwent learning using virtual laboratory learning resources, they were asked to fill out a motivation questionnaire containing their responses regarding their learning motivation after participating in High Performance Liquid Chromatography (HPLC) learning using the developed learning resources. The student motivation questionnaire consists of 30 statements. A Likert scale was used in preparing the student motivation questionnaire, with a scale range of 1-4. The data tabulation can be seen in **Table 12**.

Table 12. Data tabulation of student learning motivation questionnaire

df	Chi Kuadrat Hitung	Sig (0,05)	M ± Sdv
33	5,3818	11,07	81,4461 ± 8,8127

The data obtained from the filling of the Student Motivation Questionnaire for the experimental class was calculated with an average of 81.4461% and a standard deviation of 8.8127. Furthermore, a Normality Test was conducted on the obtained data with a calculated Chi-Squared of 5.3818, which is less than the table Chi-Squared (11.07), thus the data from the motivation questionnaire is 'Normal.'

■ **DISCUSSION**

The results of the analysis of the experimental class and control class data show an increase in learning outcomes from the pretest and posttest scores in both classes. The test used 22 multiple-choice questions with five answer options that have been validated for content and construct, with validity, difficulty level, discriminatory power, and

reliability meeting the criteria. The average increase in learning outcomes for the experimental class students is 0.7671, while for the control class it is 0.1147. From the N-Gain results, it shows that the improvement in learning outcomes for students using the Virtual Laboratory HPLC media is higher compared to teaching HPLC using student handbook learning resources. From the results of the first hypothesis test using the Two-sample t-test, it was also found that the Sig. (2-tailed) value is 0.000, which is less than 0.05. This indicates that the null hypothesis (H_0) is rejected and the alternative hypothesis (H_a) is accepted. It can be stated in testing the first hypothesis that there is an influence of using the Virtual HPLC Laboratory on the improvement of learning outcomes in analytical chemistry separation.

The research conducted by Yulina et al., (2022) shows that the use of MMI (Interactive Multimedia) assisted by HPLC simulator academically helps students increase their motivation and interest in studying HPLC material. In line with this, learning with the HPLC Simulator can develop analytical thinking skills in aspects of matching and classifying, analyzing errors, generalizing, and specifying. The study also ensures prior knowledge possessed by students regarding the basic concepts of chromatography and the basic operations of HPLC instruments so that students can use the simulator more effectively, allowing for better training in error analysis, specifying, and generalizing skills. The trial results were obtained from the research conducted by Rokhim et al., (2020), which scored 83.5% (very feasible). Practically, the developed media is beneficial for supporting practical learning. The advantages of the Virtual Laboratory include interactive connections between teachers and students, faster learning reflections, correcting and reducing misconceptions, and integration with constructivist-based learning. Thus, the use of virtual laboratories supports learning in the field of separation studies. In the research by Kartika et al. (2019), it was stated that there is a difference in the average learning outcomes and critical thinking skills between the experimental class and the control class in POE learning assisted by virtual laboratories.

The analysis results on the second hypothesis using the Independent Sample T-test obtained a t calculated value of 1.9955 > t table of 1.6900, where H_0 is rejected while H_a is accepted. The second hypothesis test states that there is a significant difference in student learning outcomes between learning with Virtual Laboratories and conventional learning. This statement is consistent with the research conducted by Bogar et al. (2023), where the data from the study shows that students participating in learning using this virtual laboratory device achieved a learning completeness level of 99.9%. Research conducted by Ariyani (2022) also proves that the increase in student learning outcomes who received Problem-Based Learning based on lesson study using virtual lab media is higher than the increase in learning outcomes for students who received conventional learning. The effectiveness of virtual laboratories in improving learning outcomes is also demonstrated in research conducted by Hutabarat and Simatupang (2024), which states that learning using Virtual Laboratories results in higher learning outcomes compared to learning with real laboratories. Learning chemistry using a virtual laboratory gives the impression of long-remembered learning, and is a good strategy for improving learning outcomes. Virtual laboratories are very interesting and are a new approach to motivate students to learn optimally (Lara & Situmorang, 2024).

In the distribution of the Learning Motivation Questionnaire for students, which has been validated with a feasibility percentage of 87.50% (very feasible), data was obtained from the completion of the questionnaire. An average score of 81.44 was achieved with a calculated Chi-Square of 3.0909 and a table Chi-Square of 11.07 in the

normality test. In the homogeneity test, the calculated Chi-Square is less than the table Chi-Square, indicating that the data obtained from the completion of the student learning motivation questionnaire is homogeneous. From this average, it can be concluded that students are motivated by the use of the Virtual HPLC Laboratory during HPLC instruction. This is due to the opinions expressed by students in the motivation survey, some of which are: the Virtual HPLC Laboratory provides ease in understanding the principles and workings of HPLC, helps students comprehend practical work with limited access to real laboratories, the Virtual HPLC Laboratory can be accessed anytime and anywhere, it is effective in terms of time, and learning becomes more interesting because the visual form of the virtual laboratory is animated, and so on.

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