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Development and Implementation of an Innovative Virtual Laboratory for Acid-Base Titrations to Improve Chemistry Learning Outcomes

Setia Lara, Manihar Situmorang*

Department of Chemistry, Faculty of Mathematics and Natural Sciences (FMIPA),
Universitas Negeri Medan,
Jl. William Iskandar Ps V, Deli Serdang, North Sumatra.

*Corresponding author: msitumorang@unimed.ac.id

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Abstract:Development and Implementation of an Innovative Virtual Laboratory for Acid-Base Titrations to Improve Chemistry Learning Outcomes. The use of virtual laboratories needs to be encouraged to adapt students' daily digital lives. This study aims to provide a virtual laboratory as multimedia for teaching Acid-Base Titration. The research was conducted involving class XI Science students, grouped into experimental class and control class. The research include providing an innovative virtual laboratory for the topic of Acid-Base Titration, and implementing it for chemistry teaching. The virtual laboratory has been packaged on a Web basis for hybrid learning, implemented in experimental classes, through short teaching, explanations on how to use virtual, and giving assignments. The control class was given conventional teaching with assignments. The research results showed virtual laboratories are effective in facilitating students' active learning. Sequential student learning outcomes from assignment results in the experimental class (M=84.80±6.90) were higher than the control class (M=78.24±7.45), posttest scores in the experimental class (M=83.00±4.95) were also higher than control class (M=65.40±7.02), and the two were significantly different (t_{-test} 10.244 > $t_{-Crit.}$ 1.677). 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.

Keywords: Virtual Laboratory, Acid-base titration, Learning outcomes, Active learning, Chemistry Teaching

Abstrak:Pengembangan dan Implementasi Laboratorium Virtual Inovatif Titrasi Asam Basa Untuk Meningkatkan Hasil Belajar Kimia. *Penggunaan virtual laboratorium perlu digalakkan untuk mengadaptasi keseharian digital siswa. Studi ini bertujuan untuk menyediakan virtual laboratorium sebagai multimedia pada pengajaran Titrasi Asam-Basa. Penelitian dilakukan melibatkan siswa kelas XI IPA, dikelompokkan menjadi kelas eksperimen dan kelas control. Tahapan penelitian meliputi menyediakan virtual laboratorium yang inovatif untuk topik Titrasi Asam-Basa, dan mengimplementasikan untuk pengajaran kimia. Laboratorium virtual telah dikemas berbasis Web untuk pembelajaran hibrid, diimplementasikan di kelas eksperimen, melalui pengajaran singkat, penjelasan cara menggunakan virtual, dan pemberian penugasan untuk pengajaran titrasi asam basa. Kelas control diberikan* *pengajaran konvensional dengan penugasan. Hasil penelitian menunjukkan bahwa virtual laboratorium efektif memfasilitasi siswa belajar aktif dan mandiri. Hasil belajar siswa secara berurutan dari hasil tugas di kelas eksperimen (M=84.80±6.90) lebih tinggi dibanding kelas kontrol (M=78.24±7.45), skor postest di kelas eksperimen (M=83,00± 4,95) lebih tinggi dibanding kelas kontrol (M=65,40± 7,02), dan keduanya berbeda secara signifikan (t-test 10.244 > t-tabel 1.677). Belajar kimia menggunakan Virtual laboratoriium memberi kesan pembelajaran lama diingat, dan menjadi strategi yang baik untuk meningkatkan hasil belajar. Virtual laboratoriium sangat menarik dan sebagai pendekatan baru untuk memotivasi siswa belajar secara optimum.*

Kata kunci: *Virtual Laboratory, Ttrasi Asam Basa, Hasil belajar, Pembelajaran aktif, Pengajaran Kimia*

• INTRODUCTION

Teaching chemistry in high school is very challenging because the knowledge students have is needed in preparation for continuing their studies at university. Knowledge of chemistry at High School (HS) level is the science foundation needed by students, especially those who will continue their studies in the field of science (Fitriyana, et al., 2023). Chemistry subjects tend to be uninteresting for school students because they are dominated by abstract concepts. In fact, chemistry teaching for cognitive mastery in schools tends to be done through memorization and practice working on questions (Abudu, et al., 2024). The delivery of chemistry concepts in some schools lacks practice due to several reasons such as limited laboratory equipment, expensive chemicals, limited study time, unavailability of resources, limited laboratory safety facilities, and other reasons. As a result, chemistry teaching is not contextual and is easily forgotten (Assi& Cohen, 2024). In this way, teaching chemistry is meaningless, it is only needed as a routine learning activity as required in the national curriculum. To overcome the problems above, it is necessary to carry out teaching that brings students directly active in teaching (Situmorang, et al., 2018). The concept of learning using virtual laboratories is one strategy for teaching students, as well as for overcoming limitations in laboratory equipment and carrying out experiments that involve the use of relatively toxic chemicals.

Learning using virtual laboratories is very good for teaching chemistry. Virtual laboratories have been used for teaching complex material, especially to demonstrate the use of equipment that is not available in the laboratory for various reasons and limitations (Muradova, 2020). The use of virtual laboratories in teaching has been proven to be effective in imparting knowledge and skills. Virtual laboratories have been used in teaching in various fields of science (Byukusenge, et al., 2022; Daineko, et al., 2017). Learning using virtual laboratories has also been implemented in chemistry teaching, because it has been successfully used to bring students to virtual learning experiences that are almost the same as real teaching in the laboratory (Kolil&Achuthan, 2024). In the current digital era, learning using virtual laboratories is very relevant and appropriate, especially in high schools. Today's students have adapted to digital life and have even moved towards digital culture and the potential of this digitalization needs to be utilized for teaching and learning activities, including teaching chemistry in high schools.

One of the chemistry topics studied in high school is Acid-Base Titration (Fikria, 2018; Rosilawati & Efkar, 2015). Knowledge about titration will be effective if combined with practical activities in the laboratory, so that students can be directly involved in knowing solutions, understanding solution concentration, understanding the occurrence of acid and base reactions, acid-base balance in chemical reactions, the concept of titer and pentiter, and titration stoichiometry (Mutambuki, et al., 2020; Situmorang, 2012). To understand all the concepts of Acid-Base Titration, students must be given knowledge and skills, which can be obtained from teaching and learning activities. The use of a virtual laboratory is a good alternative for demonstrating titration (Lara, et al., 2023). This is the basis for learning innovation using virtual laboratories. The aim of this research is to design and implement an innovative virtual laboratory for teaching acid-base titrations, to be used as a learning medium in studying the concept of acid-base titrations which can improve chemistry learning outcomes for high school students.

- **METHOD**

Population and sample

This research was carried out at SMA Negeri 1 RanahBatahan, involving class XI Science High School students who took chemistry subjects. The sample was selected purposively as many as 50 students through a homogenization technique using a pretest and simultaneously removing sample outliers. Next, the samples were grouped into experimental class and control class. The research is classified as experimental with learning treatments using virtual laboratories in the experimental group and conventional learning in the control group. Where for the design used is the Pretest-Postest Control Group Design where in two groups, the experimental and control classes are given a pretest to determine the initial state is the difference between the experimental class and the control class. The results of the good pretest experimental group did not differ significantly (Hardani, et al. 2020).

Research Procedures

The research includes the design and implementation of a virtual laboratory for teaching high school chemistry as summarized in Figure 1. The research stages include: analysis of the needs for a virtual Acid-Base Titration laboratory, virtual design for teaching Acid-Base Titration, standardization of the virtual laboratory using experts, and implementation for teaching the topic of Acid-Base Titrations in schools. The development of the Virtual Acid-Base Titration laboratory was carried out adopting the 4D model (Define, Design, Development, and Disseminate) by adapting to the topic of Acid-Base Titration. Define includes the analysis stage of the learning process as a reference in preparing learning plans. Design includes the stage of creating a virtual design for teaching Acid-Base Titration in high school. Development includes creating innovations, improvements and standardization of virtual products using experts, and Disseminate includes the implementation and dissemination stages of virtual products for teaching Acid-Base Titration.

Teaching of Acid-Base Titrations is carried out in the classroom without disturbing the teaching schedule at school. A pretest was carried out for the experimental class and control class, to measure the initial knowledge that students already had on the material to be taught. The results of this pretest are also used to homogenize the sample, namely samples that have relatively the same initial knowledge of Acid-Base Titrations, as well as to remove sample outliers from the calculation without disrupting learning in class. Furthermore, the experimental class was given teaching using a virtual laboratory and the control class was given classical teaching. Assignments and teaching and learning activities were carried out normally in two teaching groups, minus virtual laboratories in the control class. At the end of the lesson, a posttest was carried out to measure student achievement on the topic of Acid-Base Titration.

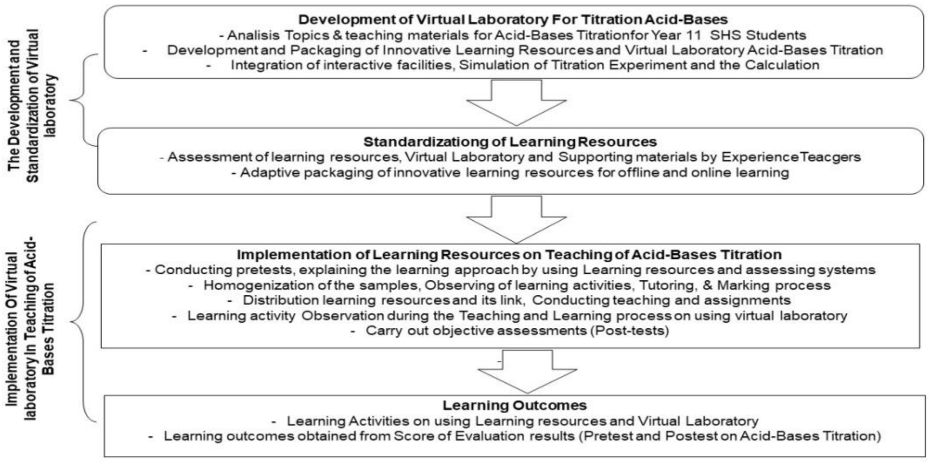

Figure 1. Development of a virtual laboratory Acid-Base Titrations for teaching High schools Chemistry.

Learning Activity Scenarios Using Virtual Laboratories

In learning activities using virtual laboratories, each group of students is required to work together in carrying out virtual Acid-Base Titration practicum, which has the same function as carrying out titration experiments in the laboratory. Students are first given an explanation of using the virtual laboratory, understanding the software used, and students are required to understand all instructions for implementing teaching and learning activities in their group. The next stage is the freedom for students to learn actively using the virtual laboratory according to the instructions given by the teacher, making observations, recording the results obtained, and carrying out calculations based on data obtained from virtual laboratory experiments. The stages of teaching and learning activities carried out in the experimental group using the virtual laboratory are summarized in Table 1.

Table 1. Teaching and learning activities using the Virtual Laboratory in Teaching Acid-Base Titration in the experimental class.

No	Learning stages	Learning activities
1	Before implementing the virtual laboratory	- Carry out Pretest - Students receive the virtual laboratory link via WhatsApp and then download it for learning purposes - Divide students into groups
2	Active learning and carrying out acid-base titrations using a	- Learn the concept of acid-base titration - Conduct experiments using a virtual laboratory

	virtual laboratory	- Record results, perform calculations and report experimental results
3	Final learning activity	- Posttest.

• RESULT AND DISCUSSION

Virtual Laboratory for Acid-Base Titration

A virtual laboratory for the topic Acid-Base Titrations has been developed for teaching chemistry in high school. The virtual laboratory consists of learning resources, animations, learning features and equipment that can provide a complete explanation of acid-base titrations. The virtual laboratory was created to be compact, informative and easy to use, to meet students' needs in carrying out learning on acid-base titration material. A brief description of the virtual laboratory for teaching acid-base titrations is summarized in Table 2.

Table 2. Brief description of the virtual laboratory as a learning medium for teaching Acid-Base Titrations.

No	Sub Topic	Contents	Short description	The Project
1	Introduction to Virtual Simulation.	Introduction to Pre-Lab of acid-base titrations.	Contains instructions menus found in the virtual laboratory for Pre-Lab and virtual laboratory simulations of Acid-Base Titration.	Acid-Base Titration Quiz and Hypelink
2	Determining indicators of learning achievement in acid-base titration.	Learning achievement indicators in Acid-Base Titrations Contains an explanation of several indicators that will be achieved when studying chemistry using a virtual laboratory.	Through the explanation of this material, students are invited to learn how to achieve learning targets in acid-base titrations according to the learning achievement indicators in Acid-Base Titrations which are determined when studying chemistry using a virtual laboratory.	Examples of questions and exercises using animated teaching media and learning videos.
3	Teaching Acid-Base Titrations and conducting animated experiments using a virtual laboratory.	Complete teaching material on the basic theory of Acid-Base Titrations, providing primary standard solutions, basic principles of titration, determining the end point of a titration and calculating the determination of analytes from experimental results using a virtual laboratory.	Students are given simulations to understand teaching material about the basic theory of Acid-Base Titrations, how to provide primary standard solutions, set up titration equipment, carry out titrations between acids and bases, see the end point of a titration using an indicator, and carry out calculations to determine the concentration of analytes from experimental results using virtual laboratory.	Carrying out Acid-Base Titration using a standard base solution of known concentration to determine the acid content in the sample using a virtual laboratory.
4	Evaluation	Solving Acid-Base Titration calculation problems.	Students are given examples of problems and their solutions, and continue with solving Acid-Base Titration calculation problems.	Acid-Base Titration Questions.

Standardization of the Acid-Base Titration Virtual Laboratory

Standardization of the Acid-Base Titration virtual laboratory as a result of the development has been carried out to ensure virtual suitability as a learning medium for teaching Acid-Base Titration. Standardization is carried out using experts, namely teachers who have experience teaching in high schools. Respondents' responses to the quality of the virtual laboratory are summarized in Table 3. The research results show that respondents strongly agree with the quality of the virtual laboratory for acid-base titration (M=3.56±0.02), which is in the very good category, and is declared suitable for implementation as a medium. learning for teaching Acid-Base Titrations.

Table 3. Standardization of the feasibility of the Acid-Base Titration Virtual Laboratory based on expert opinion.

No	Eligibility Criteria	Respondents' opinion (M±Sdv), n=3*
1	Eligibility of content	3.52±0.46
2	Systematics, presentation and animation	3.63±0.49
3	Use of language and simplicity of message	3.52±0.45
	Average	3,56 ± 0,021

*Likert scale: 4 = very good, 3 = good, 2 = bad, 1 = very bad

Implementation of Virtual Laboratories and Learning Activities

Virtual laboratory implementation has been carried out in chemistry teaching and learning activities were observed when carrying out activities using the Acid-Base Titration virtual laboratory. The learning activities observed focused on skills in carrying out scientific activities. The results of subjective assessments on student assignments using virtual laboratories are summarized in Table 4. These results show that students have used scientific steps in their teaching and learning activities. These learning activities include providing simple explanations, basic skills, concluding, further explanations, organizing strategies and tactics. The subjective value of learning activities (M=82.63±0.51) is classified as good.

Table 4. Achievements of learning activities when using the Acid-Base Titration Virtual Laboratory.

No	Leaning activities	Short description on scientific activities	Score (M±Sdv), n= 25
1	Provide a simple explanation.	Able to formulate questions and provide critical answers to consider answers and ask questions logically.	86.01±0.58
2	Basic skills	Able to use the virtual laboratory following the instructions provided in the manual.	83.21±0.47
3	Record data and draw conclusions.	Perform experiments correctly, be skilled in recording data, interpreting and drawing conclusions from virtual laboratory experiments.	80.02±0.51
4	Further explanation.	Dare to propose hypotheses from data analysis, and be able to argue to defend the results obtained.	82.01±0.45
5	Set strategy and	Able to organize strategies and tactics for	82.12±0,.54

tactics.	implementing virtual experiments in groups, showing good coordination between members in dividing data collection tasks, communicating effectively with group friends and all group members.	
	Average	82.63±0.51

Virtual Laboratory and Improving Learning Outcomes

The Acid-Base Titration virtual laboratory has been used in teaching chemistry in the experimental group and the control group was given conventional teaching as a comparison. The influence of virtual laboratories on improving learning outcomes can be seen from student achievements on assignments and learning evaluations. Student learning outcomes based on scores obtained from assignments and learning evaluations are summarized in Table 5. Pretest results show that student achievement in the experimental class (M=31.50±4.45) and control class (M=31.50±4.01), and the two are not significantly different (t_{-test}0.00 <$t_{-Crit.}$1.677). During the lesson, the assignment score was obtained, namely student achievement in the experimental class (M=84.80 6.90) and the control class (M=78.24±7.45), and both were significantly different (t_{-test}3,230 >$t_{-Crit.}$1.677). Furthermore, at the end of the lesson, the learning outcomes in the experimental class (M=83.00±4.98) were higher than those in the control class (M=65.40±7.02), and the two were significantly different (t_{-test}10.244 > $t_{-Crit.}$1.677). It was concluded that virtual laboratories are very effective in improving student learning outcomes in chemistry teaching.

Table 5. Student achievements based on scores on assignment grades and evaluation of learning outcomes in teaching Acid-Base Titration.

No	Learning Evaluation	Learning output, Score (M±sdv)		Statistical analysis (t_{-test} vs $t_{-Crit.}$)	Conclusion
		Experimental Class	ControlClass		
1	Pretest	31.50±4.45	31.50±4.20	0.00<1.677	Not different
2	Portfolio assignments	84.80±6.90	78.24±7,45	3.230>1.677	Significantly different
3	Postest	83.00±4.95	65.40±7.02	10.244>1.677	Significantly different

The relationship between learning activities and learning outcomes has been tested using Person Correlation, a correlation of 0.490 was obtained, which shows that there is a sufficient correlation category. It can be stated that there is a positive correlation between learning activities and student learning outcomes taught using an innovative virtual laboratory in teaching Acid-Base Titration.

The development of a virtual laboratory has produced virtual tools that are suitable for teaching Acid-Base Titrations. A virtual laboratory for the topic of Acid-Base Titrations has been designed, standardized and implemented for teaching in experimental classes. Learning resources with innovative virtual laboratories for teaching Acid-Base Titrations have been developed and packaged attractively to be used as learning media to facilitate active learning for students (Sary, et al., 2018). The integrated virtual laboratory learning resources and learning support devices have been assessed by experienced teachers, and have been declared suitable for use as learning media according to the characteristics of high school students, and suitable for implementation for teaching Acid-Base Titrations.

The implementation of teaching using virtual laboratories in high schools has been successful for teaching chemistry (Silalahi&Situmorang, 2024). Teaching chemistry using virtual laboratories has been carried out in high schools for teaching chemistry (Abouelenein, et al., 2024; Fitriyana, et al., 2024; Zhou, et al., 2024). Learning using virtual laboratories is very challenging for students, and relevant to the daily lives of students who have adapted to the digital world (Situmorang, et al., 2024). The learning tools succeeded in guiding students to understand and understand the concept of titration, and virtual laboratories became a substitute for teaching acid-base titrations to improve chemistry learning outcomes (Munthe, et al., 2024). Learning using virtual laboratories integrated in digital learning resources makes it easier for students to learn actively without being limited by time and place. Learning using virtual laboratories is very profitable because students can learn at any time according to their needs without being limited by classrooms and laboratories (Nainggolan, et al., 2020). Knowledge and skills can be obtained virtually because the knowledge available in digital learning resources can be practiced independently through virtual laboratories. Students can optimize their learning potential, skills and knowledge can be achieved in accordance with the desired learning targets in the curriculum (Rizki, et al., 2020).

The results of this research demonstrate that the implementation of virtual laboratories in teaching Acid-Base Titrations has influenced student learning activities in the good category (Ambarita&Situmorang, 2023). Students have used scientific steps correctly in carrying out virtual experiments, the same as scientific steps in learning science (Agustiani, et al., 2018). Laboratory skills have helped students solve problems, which has a big impact on learning activities (Sunyono&Meristin, 2022). Students successfully complete the assignments given by the teacher, and get good grades. The learning outcomes obtained in the experimental class prove that students have knowledge of the chemical material they are studying. The average chemistry learning outcomes obtained by students in the experimental class were higher than those in the control class (Hardani, et al., 2020). Chemistry learning using virtual laboratories has been able to bring students to real conditions such as those carried out in laboratories (Situmorang, et al., 2020). Teaching using virtual laboratories is very effective in overcoming the limited availability of laboratory equipment, can create meaningful learning that is the same as conducting experiments in a laboratory, and the impression of teaching is remembered longer by students. Virtual laboratories are very appropriate to be implemented in chemistry teaching which requires increased skills and knowledge.

- **CONCLUSIONS**

The implementation of teaching using virtual laboratories in high schools has been successful in improving chemistry learning outcomes. Learning resources with innovative virtual laboratories for teaching Acid-Base Titrations have been developed and packaged attractively to be used as learning media to facilitate active learning for students. The learning tools succeeded in guiding students to understand and understand the concept of titration, and the virtual laboratory facilities were effectively used as a substitute medium for practical activities. Students actively participate in optimizing their learning using virtual laboratories, and can understand the concept of titration well and carry out scientific experiments through virtual means. The average assignment value in the experimental class (M=84.80±6.90) was higher than the control class (M=78.24±7.45). Student achievement based on the final assessment showed that learning outcomes in the experimental class (M=83.00±4.98) were higher than those in the control class (M=65.40±7.02), and the two were significantly different (t_{-test} 10.244 > $t_{-Crit.}$ 1.677). Teaching chemistry using virtual laboratories has succeeded in guiding students to learn chemistry actively, and is very effective in improving chemistry learning outcomes. Virtual laboratories are worth considering for teaching other chemistry topics because they can improve skills and knowledge simultaneously.

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