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A Needs Analysis of Inquiry-Based Virtual Laboratory for Acid–Base Titration

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Abstract: *Traditional instructional methods, such as PowerPoint and video presentations, often fall short in promoting deep understanding and student engagement, particularly in complex topics like acid–base titration. This study investigates the need for innovative, inquiry-based learning resources integrated with virtual laboratories to support instructional improvement in analytical chemistry. A descriptive qualitative approach was used, involving in-depth interviews with a lecturer and a student, as well as questionnaires completed by 29 students. The findings reveal widespread dissatisfaction with current learning resources due to limitations in interactivity, completeness, and applicability. Most students strongly agreed on the need for enhanced instructional materials, inquiry-driven learning models, and simulation-based tools. A feasibility assessment of existing materials showed high scores in language clarity but highlighted the need for improvements in content quality and visual presentation. These results underscore the importance of combining guided inquiry with virtual laboratories to enhance conceptual understanding, engagement, and critical thinking. The study contributes practical insights for designing more effective learning environments in chemistry education, especially in settings with limited access to physical laboratory facilities.*

Keywords: *inquiry-based learning; learning resource; virtual laboratory; acid-base titration; chemistry education*

INTRODUCTION

The development of innovative educational resources in analytical chemistry, particularly for acid-base titration, is essential due to the limitations of traditional instructional methods (Salame et al., 2022). Research indicates that implementing interactive digital learning media can enhance student engagement and comprehension in chemistry education (Sari et al., 2025). Furthermore, a comprehensive teaching laboratory program has been shown to significantly improve students' understanding of titration principles, effectively bridging the gap between classic and modern teaching approaches (Wang et al., 2024).

Many current pedagogical approaches lack the necessary engagement and interactivity to promote deep understanding and long-term retention of complex chemistry concepts (Harahap et al., 2022). This issue is reflected in the learning outcomes of quantitative analytical chemistry at Universitas Negeri Medan, where students' average performance over the past two years has remained below 55, indicating gaps in knowledge acquisition and conceptual mastery. The lack of forward-thinking learning tools has significantly restricted students' ability to cultivate vital problem-solving and critical thinking skills—abilities that are indispensable for thriving in chemistry-related fields (Pakpahan et al., 2022).

Despite the growing recognition of inquiry-based learning, its application in acid-base titration remains limited, and many educational institutions still rely on outdated instructional methods that fail to prepare students for the practical challenges of analytical chemistry adequately (Situmorang et al., 2018). The paucity of interactive instructional materials not only undermines academic performance but also detracts from students' motivation and enthusiasm for the subject (Daeli & Silitonga, 2024; Simaremare et al., 2018). While innovative resources—such as guided inquiry-based learning—can provide students with contextual examples and structured problem-solving tasks, their availability remains scarce in many learning environments (J. Purba et al., 2019).

Higher-order cognitive abilities play a vital role in science education, particularly in analytical chemistry, where students must utilize advanced reasoning to solve complex challenges. Studies indicate that inquiry-based learning is a powerful approach for fostering these skills, as it encourages students to investigate, evaluate, and apply knowledge in diverse contexts (Satriya & Atun, 2024). This pedagogical transformation strengthens students' conceptual grasp while fostering critical problem-solving skills, ensuring their readiness for both academic achievements and professional careers (Sinaga et al., 2019). Emphasizing HOTS through guided inquiry-based learning is crucial for cultivating competent chemists who can effectively navigate modern scientific investigations (Situmorang et al., 2015).

However, despite the advantages of innovative learning approaches, significant challenges persist in teaching acid-base titration, particularly concerning the availability of laboratory infrastructure. Many institutions lack the necessary equipment and financial resources to conduct laboratory-based experiments effectively (Sary et al., 2018). Additionally, the high costs associated with chemical procurement and laboratory maintenance present further obstacles, preventing students from participating in essential hands-on learning experiences (Samosir et al., 2020; Simaremare et al., 2018). Addressing these infrastructural challenges is essential for advancing the quality of chemistry education while ensuring that every student has equal opportunities to participate in practical, hands-on learning experiences (Muis et al., 2021).

As a viable remedy, integrating virtual laboratories into acid–base titration instruction presents an innovative strategy for mitigating many of these operational constraints. These digital labs enable students to perform experiments within a controlled, interactive environment, substantially lowering costs tied to chemical procurement and lab maintenance while providing a secure setting for experimental learning (Sary et al., 2018; Simaremare et al., 2018). By simulating real laboratory experiences, virtual laboratories enable students to practice titration techniques, refine their problem-solving abilities, and gain deeper conceptual understanding—all without the risks associated with handling hazardous materials (Feszterová, 2022; Pardosi & Situmorang, 2024). This technological advancement not only resolves logistical challenges but also promotes an inclusive learning environment, where all students—regardless of access to physical lab facilities—can engage in meaningful scientific inquiry (Rizki et al., 2020).

In response to the growing demand for adaptive and student-centered educational approaches, this study aims to evaluate the instructional needs for integrating inquiry-based learning resources with virtual laboratories in acid–base titration instruction. By identifying the essential components of effective learning materials, the research seeks to not only enhance student engagement, conceptual understanding, and skill development but also to offer practical solutions for overcoming limitations in traditional laboratory teaching. The findings are expected to inform the design of accessible, interactive, and cost-effective educational tools that can support chemistry instruction in both resource-rich and resource-limited settings. Ultimately, this study contributes to improving the quality and equity of practical chemistry education through the integration of technology-enhanced learning strategies.

LITERATURE REVIEW

Needs analysis is essential for designing effective educational resources that align with student needs, fostering engagement, and improving learning outcomes. Research underscores the pivotal role of inquiry-based learning (IBL), demonstrating that student feedback is integral to enhancing both problem-solving and critical thinking skills (Dezola et al., 2023; Pulungan & Simamora, 2024). Within virtual laboratories, an effective process guarantees peak functionality while cultivating robust student engagement (Ledya et al., 2024). Studies consistently support that addressing these needs leads to more effective and impactful learning experiences across disciplines (Aryanti et al., 2020; Hannifa et al., 2022; Nwigwe, 2024).

IBL promotes active learning through exploration and investigation, significantly enhancing student comprehension in chemistry (M. I. Purba et al., 2024). It encourages questioning and experimentation, which strengthens understanding of scientific concepts (Nurhayati & Iryani, 2022; Rizal & Fitriza, 2021). In acid-base titration, IBL methods have demonstrated effectiveness in reinforcing conceptual knowledge (Nurhayati & Iryani, 2022; Tatsuoka et al., 2015). The integration of digital tools, including virtual laboratories, expands experiential learning opportunities and supports deeper engagement (Priyatni et al., 2020; Xie et al., 2017). These innovations facilitate collaborative inquiry and improve knowledge retention (Sypsas et al., 2020).

Virtual laboratories play a crucial role in enhancing students' conceptual understanding in chemistry education by providing an interactive platform for exploring complex scientific phenomena. Research demonstrates the effectiveness of virtual labs in practical chemistry topics, with specific studies highlighting improvements in understanding acid-base titration concepts through simulated environments (Erni, 2019). For example, the implementation of a virtual laboratory specifically designed for acid-base titration tasks has shown significant enhancement in learners' conceptual grasp compared to traditional methods (Erni, 2019; Siallagan et al., 2024). However, the integration of virtual labs is not without challenges; while they offer accessibility and flexible learning opportunities, issues related to technology adoption, user familiarity, and the potential lack of realism in simulations can hinder their effectiveness (Wahyudi et al., 2024). The literature also identifies opportunities for improvement, such as refining simulations to better mimic real-life laboratory conditions and enhancing user interactivity to engage students actively (Darby-White et al., 2019; Putra & Zainul, 2024). As virtual laboratories continue to evolve, they present a promising avenue for enriching chemistry education, particularly when strategically integrated with existing curricula to support deeper learning and practical skill development (Pavitasari et al., 2025; Sopari et al., 2024).

Acid-base titration is a fundamental technique with widespread applications in science. However, challenges such as misconceptions about chemical equilibria and difficulty interpreting titration curves affect learning outcomes (Priyatni et al., 2020; Salame et al., 2022). Research suggests diverse instructional strategies, including self-regulated learning and technology-enhanced visualization tools, improve student understanding (Mulyani et al., 2023; Salsabila & Muchlis, 2024). Digital tools enhance understanding and connect theoretical concepts with practical laboratory skills (Fernandez-Maestre, 2020; Pierre, 2019).

The integration of IBL with virtual laboratories (vLabs) is increasingly recognized as an effective strategy in chemistry education. Studies show that this approach enhances engagement, conceptual understanding, and problem-solving skills (Faresta et al., 2023; Sypsas et al., 2020). Structured frameworks, such as the one proposed by West *et al*., offer a systematic method for inquiry-based learning within virtual settings, improving student outcomes in titration experiments (West et al., 2021). However, gaps remain in assessing long-term impacts, scalability, and optimal educational contexts for IBL-vLab integration (Chen et al., 2025; Fegely et al., 2020). Addressing these gaps will further refine the effectiveness of this approach in chemistry education.

This study assumes that current instructional media for acid–base titration do not adequately support student learning, particularly in fostering deep conceptual understanding and practical skills. It also assumes that integrating inquiry-based methods with virtual laboratory simulations will better meet students' learning needs and improve learning outcomes.

METHODS

A descriptive qualitative methodology underpinned this study. The descriptive qualitative method was chosen as it allows for a deeper understanding of students' and educators' perspectives regarding instructional needs. Qualitative research is appropriate for exploring complex phenomena within educational contexts through rich descriptive data (Creswell & Creswell, 2022). The participants included one instructor responsible for course delivery and 29 students who had previously engaged in acid–base titration within the qualitative and quantitative analytical chemistry course offered by the Department of Chemistry, Faculty of Mathematics and Natural Sciences at Universitas Negeri Medan. The research object is the acid-base titration instructional materials utilized in the course. In March 2025, the study was carried out in the Department of Chemistry, Faculty of Mathematics and Natural Sciences at Universitas Negeri Medan.

Data collection instruments included interview sheets, questionnaires, and a modified version of the teaching material assessment instrument originally designed by the Badan Standar Nasional Pendidikan (BSNP). Interviews were conducted with a lecturer and a student to gain insights into the instructional materials and the acid-base titration learning process that has been implemented. The survey was conducted with 29 students to identify their educational requirements for inquiry-based learning materials combined with a virtual laboratory focused on acid-base titration. An assessment of the instructional materials' feasibility was performed using the BSNP instrument to evaluate the appropriateness of the learning resources currently in use.

The data derived from interviews will be analyzed descriptively, while the questionnaire responses and feasibility assessment results will be converted into percentage values through an established formula.

$$P = n/N \times 100\% \quad (1)$$

Where:
P = Percentage of score obtained
n = Total score obtained
N = Total prescribed score

(Sudjana, 2005)

For example, if a statement obtains a total score of 100 out of a maximum of 145 points, the percentage is calculated as follows:

$$P = 100/145 \times 100\% = 69\%$$

The classification of percentages derived from the questionnaire will adhere to the criteria established in Table 1. Likewise, the percentages obtained from the feasibility assessment will be systematically categorized following the guidelines outlined in Table 2.

Table 1. Response Criteria

Interval of Percentage (%)	Criterion
0 – 20	Strongly Disagree
21 – 40	Disagree
41 – 60	Neutral
61 – 80	Agree
81 – 100	Strongly Agree

(Sugiyono, 2014)

Table 2. Feasibility Criteria

Interval of Percentage (%)	Criterion
25 – 43	Not Feasible
44 – 62	Less Feasible
63 – 81	Feasible
82 – 100	Very Feasible

(Arikunto, 2018)

RESULT AND DISCUSSION

Interview with A Lecturer

As summarized in Table 3, the lecturer reported that instruction in acid–base titration primarily relies on PowerPoint and video. These media were considered insufficient due to limited depth and weak engagement. Students often show low motivation for independent learning and disengage from video content. The lecturer noted that essential information, such as detailed calculations, is often missing, necessitating additional resources like modules or textbooks. Laboratory practicum, while routinely conducted, was limited by time constraints and insufficient assistant support, leading to its cancellation for the current cycle. The lecturer emphasized the need for a virtual laboratory as an alternative learning strategy.

Table 3. Summary of Interview Responses from the Lecturer

Aspect	Lecture Response
Media Used	PowerPoint, Video
Strengths	Language clarity
Weaknesses	Limited depth, low engagement, no detailed explanation
Practicum Issues	Time constraints, lack of lab assistants, and the practicum were cancelled
Media Suggestions	A virtual lab is needed to enhance engagement and overcome lab limitations

This result reflects broader challenges in chemistry education, where traditional tools fail to support inquiry and critical thinking (Simaremare et al., 2018). The implication is that instructors require more interactive, structured media that support deeper conceptual engagement and flexible practicum alternatives.

Interview with A Student

Student responses (Table 4) echoed the lecturer's concerns. The dominant use of PowerPoint was seen as ineffective, especially in delivering calculation content and offering explanations beyond bullet points. Though the student had performed a titration practicum, it was limited to basic titrations and lacked clarity in identifying titration endpoints. The student expressed strong support for adopting virtual laboratories that allow repeated and flexible practice.

This feedback confirms that current media not only under-deliver in content but also miss opportunities for inquiry and student autonomy. Instructional formats that neglect interactivity limit procedural skill development and engagement (Mahaffey, 2020; Penn & Mavuru, 2020). The implication is that media must be redesigned to offer structured yet flexible inquiry tasks that simulate hands-on experience.

Table 4. Summary of Interview Responses from the Student

Aspect	Lecture Response
Media Used	PowerPoint
Strengths	Some visual aids
Weaknesses	No depth, lacking explanation of procedures, and calculations are not clear
Practicum Experience	Conducted, but only for strong acid-base, endpoint unclear
Media Suggestions	Supports the use of a virtual lab for better understanding and repeated practice

Need Analysis Questionnaire

The questionnaire administered to 29 students revealed strong support for enhancing current instructional methods. A significant majority (85%) strongly agreed on the need for improved learning resources, while 79% supported the use of simulation and visualization tools. Additionally, 78% agreed that incorporating an inquiry-based approach would benefit their understanding, and 72% acknowledged the importance of virtual laboratories as an alternative to physical practicum. These findings indicate that students recognize both the limitations of current resources and the value of more interactive, technology-supported learning tools.

Table 5. Student Agreement on Aspects ofInstructional Needs

Aspects of Needs	Percentage (%)	Criteria
Learning Resource	85	Strongly Agree
Inquiry Approach	78	Agree
Simulation and Visualization	79	Agree
Virtual Laboratory	72	Agree

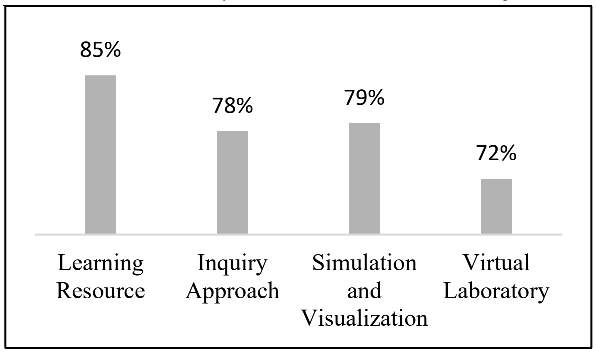

Figure 1. Bar Chart of Student Agreement on Instructional Needs

These data indicate strong student preference for modernized, inquiry-based tools that allow exploration, visualization, and contextual learning. The lower—though still strong—support for virtual labs suggests that while students may be less familiar with digital experimentation, they are open to integrating it into their learning process.

The implication here is clear. Instructional design must evolve to meet student expectations for engaging and hands-on learning. Curriculum planners should integrate simulation tools and inquiry models that enhance student agency and bridge the gap between theory and practice (Nurhayati & Iryani, 2022; Peechapol, 2021).

Feasibility Assessment of PowerPoint

The feasibility of current PowerPoint materials was assessed using the BSNP instrument (Table 6). Scores across three categories are illustrated in Figure 2:

Table 6. Feasibility Scores of Power Point-Based Learning Materials

Aspects	Percentage (%)	Criteria
Content	66.75	Feasible
Language	87.50	Very Feasible
Presentation	55.25	Less Feasible
Average	69.83	Feasible

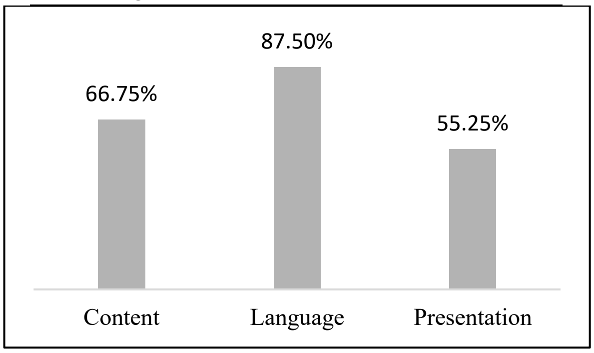

Figure 2. Feasibility Scores by Aspect

While the language was positively rated, the content lacked sufficient depth, and the presentation design was rated as weak, likely due to static formatting and minimal visual engagement. These findings support earlier claims that traditional media do not adequately support guided inquiry or meaningful visualization.

This reinforces the need to modernize chemistry instruction by integrating media that are both pedagogically sound and visually dynamic. Interactive simulations and virtual labs can serve as effective replacements for text-heavy slides, offering real-time feedback and immersive exploration (Bartosh et al., 2023; Sypsas et al., 2020).

The integration of virtual laboratories with guided inquiry principles presents a scalable, cost-effective, and pedagogically rich solution to long-standing instructional challenges. The proposed model is designed not merely as a digital supplement, but as a structured learning pathway—enabling hypothesis formation, experimentation, analysis, and reflection. This aligns with calls from recent literature (Faresta et al., 2023;

Sypsas et al., 2020) while adding the novelty of a needs-driven design rooted in actual student and lecturer input.

For students, the media provide increased access to conceptual and procedural practice in a safe, repeatable format. For curriculum designers and educators, the findings offer practical guidance for creating adaptable, student-centered chemistry instruction, especially in resource-limited environments where real lab access is restricted.

CONCLUSION

This study identified key limitations in current instructional media for acid–base titration, particularly the lack of interactivity and conceptual depth in traditional tools. Through interviews, questionnaires, and feasibility analysis, the research revealed a strong demand for more engaging and inquiry-driven learning experiences. In response, this study introduces a novel instructional framework that positions a virtual laboratory not as a supplement but as a core medium integrated with guided inquiry. This approach enables students to explore, hypothesize, and reflect in a digital setting that mimics real laboratory processes. The model offers a practical and scalable solution to improve student understanding and engagement, particularly in resource-limited contexts, and provides clear implications for curriculum design and instructional innovation in chemistry education.

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