A Review of Computer-Based Simulations for Acid-Base Titration Experiments in Ordinary Level Chemistry

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Abstract: Chemistry is a core science subject at Ordinary Level and plays a vital role in helping students understand the nature and behavior of substances through both theoretical learning and practical experimentation. One of the most important practical topics in Ordinary Level Chemistry is acid-base titration, which develops students' skills in measurement, observation, and calculation. However, in many secondary schools, large class sizes, limited laboratory space, and insufficient equipment restrict students' opportunities to actively participate in practical experiments. As a result, acid–base titration is often taught mainly through demonstrations or theoretical explanations, leading to poor practical understanding and low confidence among learners. This project presents a review and design of a computer-based, web-based simulation system for acid–base titration experiments aimed at supporting Ordinary Level Chemistry teaching and learning. The proposed system simulates a virtual laboratory environment where students can interact with titration apparatuses such as burettes, pipettes, conical flasks, and indicators. The system allows learners to perform experiments repeatedly, observe color changes at end points, record volume readings, and carry out necessary titration calculations with immediate feedback. Findings from recent studies between 2021 and 2026 indicate that virtual laboratory simulations significantly improve students' conceptual understanding, practical skills, motivation, and academic performance in Chemistry. Therefore, the proposed simulation system is expected to complement traditional laboratory sessions, reduce challenges caused by large class sizes, and enhance students' practical competence and confidence in acid–base titration experiments.
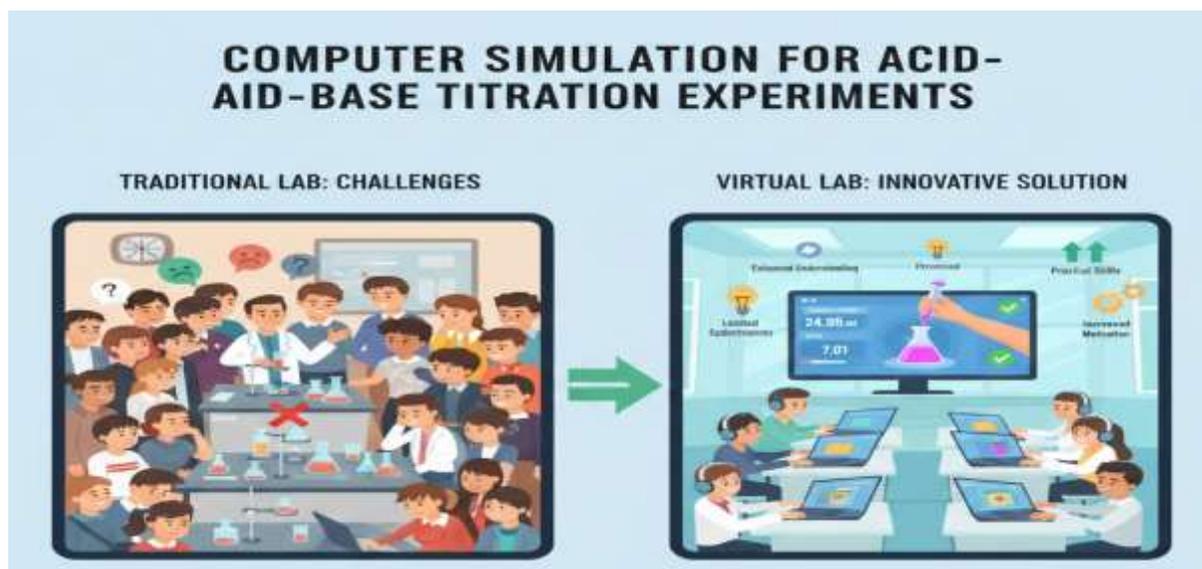
Figure 1 Old challenges and modern visual lab

Keywords— Acid-Base Titration; Visual Laboratory; Computer Simulation; Chemistry Education; Web Based Learning

1.0 INTRODUCTION

Chemistry is a core science subject taught at Ordinary Level and plays an important role in helping everyday life[1]. students understand how different substances interact and react in The subject integrates theoretical knowledge with practical experiments to enable learners to develop a clear and meaningful understanding of chemical concepts[2]. One of the key practical topics in Ordinary Level Chemistry is acid–base titration, through which students learn essential skills such as measuring solution concentrations, reading volumes

accurately, identifying end points, and performing calculations based on experimental data.

In a standard chemistry laboratory, acid-base titration experiments require the use of apparatuses such as burettes, pipettes, conical flasks, indicators, and standard solutions. Practical sessions allow students to apply theoretical knowledge, follow correct laboratory procedures, and gain hands-on experience in handling laboratory equipment[3]. These activities are important for building confidence and competence in practical chemistry.

However, effective practical learning also depends on the laboratory environment and the number of students it accommodates[4][5]. In many secondary schools, the number of students enrolled in a class is often much larger than the capacity of the chemistry laboratory[6]. This situation makes it difficult for every student to actively participate in experiments during practical sessions. As a result, experiments are sometimes demonstrated by teachers or performed by a few students while others observe, limiting individual hands-on experience[7].

When students do not get enough opportunities to personally perform titration experiments, they may find it challenging to fully understand the procedure. Difficulties often arise in reading burette measurements, identifying the correct end point, and applying calculation formulas accurately[8],[9]. This gap between observation and direct practice can affect students' understanding and performance in examinations, especially in practical-oriented questions.

With the rapid advancement of information and communication technology, computer-based simulation systems have become an effective approach to support teaching and learning in science subjects[10],[11]. Simulation technology can create a virtual laboratory environment where students can perform experiments independently without physical space limitations[12]. Such systems allow learners to repeat experiments many times, explore different scenarios, and learn at their own pace in a safe and controlled environment[13].

This project therefore focuses on the design and implementation of a computer-based simulation system for acid–base titration experiments for Ordinary Level Chemistry[14]. The proposed system will provide a realistic virtual laboratory where students can interact with titration apparatuses, observe the flow of solutions, experience simple laboratory sounds, and carry out all necessary titration calculations[15]. The system will also allow users to select different acids, bases, and indicators to observe their effects during the titration process.

By using this simulation system, students are expected to gain a deeper understanding of acid–base titration procedures and improve their practical skills. The system is intended to support both teachers and students by complementing traditional laboratory sessions, reducing the challenges caused by large class sizes, and making the teaching and learning of titration experiments more effective, engaging, and practical.

1.1 BACKGROUND

Acid–base titration plays a key role in helping students connect theory with practice. During a real titration experiment, learners are expected to follow correct procedures, add solutions carefully, observe the end point, and record volume readings accurately[16]. These activities help students build confidence and understanding in practical Chemistry and prepare them for both examinations and further scientific studies[17].

However, effective practical learning depends greatly on the learning environment[18]. In many secondary schools, especially in developing countries, the number of students enrolled in Chemistry classes is often much larger than the size of the laboratory[19]. This situation limits the opportunity for every student to actively perform experiments. In most cases, only a few students are able to handle the apparatus while others observe, or practical work is demonstrated by the teacher due to time and space limitations. As a result, many students do not get enough hands-on experience in performing acid–base titration experiments[20].

Because of this limitation, acid–base titration is often taught mainly in theory. Students may memorize experimental steps from textbooks or teacher explanations without practicing the experiment themselves[21]. This makes it difficult for learners to understand important aspects such as accurate burette reading, recognizing the correct end point, and applying formulas using real experimental values[22]. Consequently, students may perform poorly in examinations and develop low interest and confidence in Chemistry practical work[23].

With the advancement of information and communication technology, virtual or computer-based laboratory systems have been introduced as a supportive solution for practical science learning[24]. Virtual laboratories simulate real laboratory environments on computers or mobile devices, allowing students to perform experiments without physical laboratory space. These systems enable learners to practice experiments repeatedly, learn at their own pace, and make mistakes safely without damaging equipment or risking accidents[25].

Research conducted from 2021 to 2026 strongly supports the use of virtual laboratories in Chemistry education.

In 2021, Sari, Supurwoko, and Nugroho reported that students who used virtual laboratories for acid–base titration showed improved critical thinking skills and better understanding compared to those taught using traditional methods[26]. Similarly, Widodo et al. in 2021 found that virtual laboratory users achieved higher academic performance due to repeated practice and independent learning opportunities[27].

In 2022, Rahmawati and Putra demonstrated that integrating guided inquiry with virtual laboratories made students more active and improved their understanding of titration steps and calculations[28].

Kurniawan, Suryadi, and Lestari in 2023 confirmed that virtual laboratories for acid-base titration were valid, reliable,

and effective as learning tools, especially for preparing students before entering real laboratories[29]. Other researchers in the same year also noted that virtual environments increased student confidence and reduced fear of making mistakes during experiments[30].

Research in 2024 shifted towards web-based and interactive virtual laboratories. Studies by Mashauri et al. and Setiawan and Hakim showed that students who used web-based and augmented reality-supported virtual laboratories were more motivated and achieved higher scores in assignments and post-tests than those who relied only on traditional teaching methods[31].

In 2025, Adeyemi, Balogun, and Yusuf found that students who learned Chemistry practicals using virtual laboratories demonstrated better long-term retention and understanding of concepts[32]. Mobile-based and game-style virtual laboratory applications[33] studied by Pratama et al. in 2025 also increased student interest and simplified difficult parts of acid–base titration, such as endpoint detection and burette reading[34].

Most recently, studies in 2026, such as that by Zhang and Liu, emphasized the need for simple, accessible, and web-based virtual laboratory systems that align closely with school curricula and examination requirements[35]. These researchers highlighted that such systems are particularly important in learning environments with large class sizes and limited laboratory access[36].

Overall, studies conducted between 2021 and 2026 clearly show that virtual laboratory tools play an important role in improving students' understanding, practical skills, motivation, and academic performance in Chemistry. These findings indicate a strong need to design and implement a simple, realistic, and web-based acid-base titration simulation system tailored for Ordinary Level Chemistry students. The proposed system will support practical learning, reduce challenges caused by large class sizes, and help students gain meaningful hands-on experience in a virtual laboratory environment.

1.2 PROBLEM STATEMENT

One of essential practical topic in Ordinary Level Chemistry is Acid–base titration because it develops students' skills in measurement, observation, and calculation. For students to master these skills, they must actively participate in experiments and practice the procedures themselves. However, in many secondary schools, the number of students enrolled in Chemistry classes is much higher than the capacity of available laboratory spaces, making it difficult for every learner to gain sufficient hands-on experience during practical sessions.

Due to limited time and large class sizes, practical lessons are often conducted through demonstrations or shared group work, where only a few students actively perform the experiment while others observe[37]. As a result, many learners complete their studies without personally practicing important skills such as accurate burette reading, proper endpoint identification, and linking calculations to real experimental observations[38]. This limitation reduces students' confidence and understanding when handling titration-related questions, especially in practical examinations[39].

Teachers also face challenges in ensuring effective practical learning under these conditions. It is difficult to monitor and assess individual students' practical skills when many learners must share limited laboratory time[40]. This situation limits opportunities for personalized guidance, immediate correction of mistakes, and repeated practice, all of which are essential for mastering acid–base titration.

Although some digital and virtual laboratory tools exist, many of them are either too basic, lack realistic interaction, or do not provide meaningful feedback on students' actions and calculations[41]. In addition, some systems are not easily accessible outside the classroom or are not well aligned with the Ordinary Level Chemistry syllabus. As a result, these tools do not fully support independent practice or skill development[42].

Therefore, there is a clear need for a realistic, interactive, and web-based acid–base titration simulation system designed specifically for Ordinary Level Chemistry students. The system should allow learners to practice experiments repeatedly, make measurements, perform calculations, and receive immediate feedback in a virtual environment. Such a system will help students develop practical understanding and confidence, even when direct laboratory practice time is limited.

By addressing the challenge of limited hands-on opportunities caused by large class sizes, the proposed system is expected to improve students' practical skills, examination performance, and interest in Chemistry. It will also support teachers by providing an effective teaching and practice tool that complements existing laboratory sessions and enhances practical learning outcomes.

1.3 OBJECTIVES OF THE PROJECT

1.3.1 Main Objective
To design and implement a web-based acid–base titration simulation system that enhances Ordinary Level Chemistry students' understanding of practical experiments, improves their calculation and observation skills, and provides teachers with a safe and interactive teaching tool.

1.3.2 Specific Objectives
1. To develop a user-friendly virtual laboratory interface that simulates acid–base titration apparatus, including burettes, pipettes, conical flasks, and indicators, allowing students to perform experiments safely and repeatedly, forming the foundation for further practical learning.
2. To implement real-time measurement and calculation features in the system that enable students to record volumes, calculate concentrations, and link experimental actions with results, building directly on the interactive environment created in the first objective.
3. To provide immediate feedback and error detection mechanisms that guide students in identifying mistakes, understanding end points, and reinforcing practical skills,

ensuring that calculations and observations from the previous step are meaningful and actionable.

4. To evaluate the effectiveness of the simulation system by assessing students' practical understanding, calculation accuracy, and confidence before and after use, confirming the impact of the system after interaction, calculation, and feedback have been.

2.0 RELATED WORKS

The body of work on virtual laboratories in science and chemistry education reflects a broad and growing interest in digital simulation technologies as tools for supporting student learning, engagement, and practical skill acquisition. Beyond acid–base titration, numerous studies have examined how virtual lab environments can enhance experimental skills and conceptual understanding across STEM disciplines. For example, Allen Baume in 2025 investigated the use of virtual laboratory simulations to support the acquisition of experimental chemistry skills, finding that students who interacted with simulated experiments showed improved procedural understanding and greater confidence in laboratory tasks, particularly when simulations were integrated with structured instructional activities. Research on high school learners also demonstrates positive outcomes; for instance, a study on virtual laboratories' ability to enhance experimental skills and scientific understanding found that students reported increased competence in following scientific procedures and manipulating variables within a safe, simulated environment, suggesting that virtual labs can effectively supplement or extend traditional practical experiences.

Specific to chemistry topics, research on Android and mobile virtual chemistry tools like VC.LAB shows that interactive mobile applications can make abstract concepts such as acid–base titration more accessible and engaging for learners by embedding simulation features with game like elements[43]. Similarly, studies that developed and implemented web based virtual laboratories for titration have revealed significant improvements in students' active learning outcomes when compared with traditional instruction, indicating that carefully designed simulation systems can facilitate deeper conceptual understanding and long-term retention of chemistry knowledge. In the broader context of science education, research on virtual reality (VR) frameworks such as the V Lab VR Educational Application Framework illustrates how immersive environments can be utilized to simulate complex laboratory processes across subjects including chemistry and biology, helping learners visualize scientific phenomena that are difficult to observe in real settings. Moreover, studies assessing learning in immersive VR environments have emphasized that curriculum based virtual science experiences can improve engagement and comprehension, though research in this area continues to explore how best to integrate immersive tools into formal instructional strategies[44].

Augmented reality (AR) has also emerged as a complementary technology that enhances virtual laboratory experiences by overlaying digital information on real environments[45]. For example, Putri and Sukarmin in 2024 developed an AR based virtual laboratory for acid–base titration, finding that students responded positively to the application's interactive and visual features, which contributed to higher learning outcomes and student engagement when compared to traditional instruction. Another study involving needs analysis for high school AR virtual labs highlighted teachers' and students' expectations for realistic simulations, 3D animations, and accessible mobile compatibility, indicating that user centered design is critical for the adoption and effectiveness of AR virtual laboratories in chemistry education[46].

In addition to specific chemistry applications, research into general virtual laboratory platforms such as Labster shows that virtual laboratories can be highly effective learning tools when used to complement conventional instruction[47]. Studies of Labster implementation reported that virtual simulations increased student engagement, motivation, and academic performance in science courses, with students and instructors recognizing virtual labs as valuable preparatory tools before hands on experiments. Similarly, research into game based virtual chemistry classrooms in metaverse environments points to innovations in remote and interactive learning, demonstrating how immersive simulations and gamification can support deeper engagement with complex scientific concepts in ways that traditional labs may not easily provide[48].

Comparative analysis of real experiments and digital ICT simulations also suggests that a hybrid approach where virtual simulations are used to introduce and reinforce concepts while real labs build methodological consistency may be the most promising strategy for supporting comprehensive science education, as it combines the strengths of both approaches[49]. Together, these related works indicate that virtual laboratories and simulation technologies are not only effective in enhancing science learning outcomes but also continually evolving in terms of platforms, pedagogical integration, and user interaction, thereby providing a fertile foundation for developing a targeted web based acid–base titration simulation system for Ordinary Level learners[50].

2.1 Role Computer Simulations in Chemistry Learning

Empirical studies have consistently shown that computer simulations play a crucial role in enhancing students' learning, particularly in practical subjects like Chemistry. For instance, Sari, Supurwoko, and Nugroho in 2021 found that students who used virtual laboratories for acid–base titration demonstrated higher critical thinking and better conceptual understanding than those taught using traditional classroom methods. The simulation allowed learners to visualize chemical reactions, repeat experiments, and actively engage with the procedures, showing that computer simulations improve both understanding and retention[51].

Similarly, Widodo et al. in 2021 reported that interactive computer simulations enable students to practice experiments safely, make independent observations, and correct mistakes

in real time[52]. Their study highlighted that simulations enhance practical skills, such as accurate measurement, observation of color changes, and performing calculations, while increasing student confidence in handling laboratory tasks[53].

In 2022, Rahmawati and Putra integrated guided inquiry with virtual simulations and found that students became more active learners, better able to follow experimental procedures, and more accurate in their calculations. The study emphasized that computer simulations facilitate structured learning while giving students flexibility to explore and learn from mistakes, a key role in practical science education[54].

By 2023, researchers such as Kurniawan, Suryadi, and Lestari confirmed that web-based virtual laboratories serve as effective teaching and learning tools[55]. Their study showed that simulations not only enhance students' understanding of titration procedures but also increase engagement and motivation, allowing learners to practice safely without consuming real chemicals[56]. Likewise, Ongowo and Indoshi in 2023 found that students using virtual labs developed more confidence and were less intimidated by practical experiments, highlighting the motivational role of simulations in learning.

Further studies in 2024, including Mashauri et al. and Setiawan and Hakim, reported that web-based and augmented reality-supported virtual labs make learning more interactive and accessible. Students were able to connect theoretical knowledge with practical application, observe experiment outcomes in real time, and receive immediate feedback, which enhanced their understanding and performance[57].

Research in 2025, such as Adeyemi, Balogun, and Yusuf, emphasized that computer simulations improve long-term retention of practical knowledge. Students who repeatedly practiced acid–base titration in virtual environments retained experimental procedures and calculation skills better than peers who only had traditional lessons[58]. Pratama et al. also found that mobile-based and game-style virtual labs increased student interest and simplified difficult experimental steps, such as endpoint detection and burette reading.

Finally, in 2026, Zhang and Liu highlighted that lightweight, web-based simulations provide an accessible platform for large classes, allowing all students to practice experiments repeatedly. Their findings showed that simulations help learners develop competence, improve understanding, and gain confidence, which are critical for mastering practical Chemistry skills[59].

2.2 Virtual Laboratories and Acid–Base Titration

Tatli and Ayas conducted a study on the use of virtual laboratories in teaching chemistry experiments, including acid–base titration[60]. The study involved secondary school students and used a quasi-experimental research design[61]. Data were collected through achievement tests and student questionnaires. The results indicated that students who used virtual laboratories performed better in understanding experimental procedures and interpreting results compared to those who relied solely on physical laboratory experiments.

The researchers noted that virtual laboratories were particularly useful in schools with limited laboratory resources. Despite these positive findings, the study did not focus specifically on Ordinary Level curricula and did not consider how simulations could be aligned with national examination requirements, which creates a gap addressed by the present study[62].

2.3 Simulation-Based Learning and Conceptual Understanding

A study by de Jong and van Joolingen investigated how simulation-based learning environments support conceptual understanding in science education. The study emphasized learner interaction with simulation models and how experimentation within virtual environments enhances knowledge construction[63]. The findings showed that simulations are effective in promoting deeper understanding when learners are guided appropriately. However, the researchers also found that unguided simulations could lead to misconceptions if students are not properly supported. The study focused on general science learning and did not specifically examine acid–base titration or Ordinary Level chemistry learners. Therefore, there is a need for research that combines simulation with appropriate instructional guidance in the context of O-Level acid–base titration experiments[64].

2.4 Technology Integration in Secondary School Chemistry

Kiboss, Ndirangu, and Wekesa conducted a study on the impact of computer-based instruction on secondary school students' achievement in chemistry. The study used an experimental design involving students from public secondary schools[65]. The results showed that students taught using computer-assisted instruction performed significantly better than those taught using traditional methods. The study also reported increased student motivation and interest in chemistry lessons. However, the research focused on general chemistry topics and did not examine specific practical experiments such as acid–base titration. Additionally, the study did not explore the use of interactive simulations that allow manipulation of experimental variables, which the current study aims to incorporate[66].

2.5 Virtual Experiments in Resource-Limited Schools

In 2021 Makransky, Thisgaard, and Gadegaard examined the use of virtual laboratory simulations in science education, particularly in environments with limited physical laboratory resources. The study employed a mixed-methods approach, combining test scores and student feedback. The results indicated that virtual experiments improved conceptual understanding and learner confidence, especially when physical laboratory access was restricted. Despite these benefits, the study did not focus specifically on Ordinary Level chemistry or acid–base titration experiments. Furthermore, it did not assess how such simulations could

support curriculum-based learning objectives at the secondary school level, which is a focus of the current study[67].

3.0 OBSERVATIONS

From the reviewed literature (2021–2026), several important observations can be drawn regarding the teaching and learning of acid–base titration using virtual and computer-based simulation systems.

First, the literature consistently shows that acid–base titration is a challenging practical topic for many secondary school students. Studies indicate that learners experience difficulties in accurate burette reading, correct identification of the end point, and proper application of calculation formulas when they lack sufficient hands-on practice. This challenge is strongly associated with overcrowded classrooms, limited laboratory facilities, and insufficient time allocated for practical sessions, particularly in developing countries.

Second, it is observed that large class sizes and limited laboratory resources significantly restrict students' active participation in practical chemistry experiments. In many schools, titration experiments are often demonstrated by teachers or performed by a small group of students while others observe. As a result, many learners complete their studies without adequately practicing essential titration skills, leading to low confidence and weak performance in practical examinations.

Third, the reviewed studies clearly demonstrate that computer-based simulations and virtual laboratories positively influence students' understanding and performance in chemistry practicals. Virtual laboratories allow learners to repeat experiments multiple times, practice independently, and learn at their own pace without the risk of chemical hazards or equipment damage. Students using virtual simulations consistently show improved conceptual understanding, higher motivation, better calculation accuracy, and increased confidence compared to those taught using traditional methods alone.

Fourth, recent research trends indicate a shift towards web-based, mobile-based, and interactive virtual laboratory systems. Studies from 2024 to 2026 emphasize that web-based and lightweight simulation platforms are more accessible and suitable for schools with limited infrastructure. Augmented reality and game-based elements further enhance learner engagement, although such technologies are often complex or require high-end devices, limiting their widespread adoption in ordinary secondary schools.

Another important observation is that many existing virtual laboratory systems are not fully aligned with Ordinary Level Chemistry curricula and examination requirements. While several simulations are effective for higher education or general science learning, they often lack syllabus-specific content, structured guidance, real-time calculation validation, and feedback mechanisms that support O-Level assessment standards. This limits their effectiveness for direct examination preparation.

Finally, the literature reveals that there is a strong need for simple, realistic, and curriculum-aligned simulation systems that focus specifically on Ordinary Level acid–base titration. An effective system should simulate real laboratory apparatus, support accurate measurements, guide learners through correct procedures, provide immediate feedback on errors, and reinforce calculation skills. Such a system would complement physical laboratory sessions, address challenges caused by large class sizes, and enhance practical learning outcomes.

Overall, the observations from the reviewed literature strongly justify the development of a web-based acid–base titration simulation system tailored for Ordinary Level Chemistry students, as proposed in this project.

4.0 CONCLUSION

This review paper examined existing literature on the teaching and learning of acid–base titration in Chemistry, with particular emphasis on the use of computer-based simulations and virtual laboratory systems between 2021 and 2026. The reviewed studies clearly indicate that acid–base titration is a critical practical topic in Ordinary Level Chemistry, yet its effective teaching is often constrained by large class sizes, limited laboratory facilities, insufficient equipment, and restricted time for hands-on practice.

The literature consistently shows that when students lack direct involvement in practical experiments, they experience difficulties in essential skills such as accurate burette reading, correct identification of end points, and proper application of titration calculations. These challenges negatively affect students' confidence, motivation, and performance in practical examinations. Teachers also face challenges in monitoring individual learners and providing adequate guidance during crowded laboratory sessions.

Findings from multiple studies confirm that computer-based simulations and virtual laboratories provide an effective solution to these challenges. Virtual laboratory systems enable students to perform experiments independently, repeat procedures multiple times, and safely explore experimental processes without the limitations of physical laboratory space or resources. Evidence from recent studies demonstrates that students who use virtual simulations show improved conceptual understanding, higher calculation accuracy, increased confidence, and greater interest in Chemistry practical work.

However, the review also reveals that many existing virtual laboratory systems are not fully aligned with Ordinary Level Chemistry curricula and examination requirements. Several tools are designed for higher education or general science learning and lack syllabus-specific content, structured guidance, real-time calculation feedback, and realistic simulation of titration apparatus suitable for O-Level learners. This limitation reduces their effectiveness in supporting examination-oriented practical learning.

Based on these findings, the literature strongly supports the need for a simple, accessible, and web-based acid–base titration simulation system specifically designed for Ordinary Level Chemistry students. Such a system should closely reflect real laboratory procedures, support accurate measurements and calculations, provide immediate feedback, and align with national syllabus and assessment standards. The development and implementation of this type of simulation system is expected to enhance practical understanding, improve examination performance, and complement traditional laboratory sessions, particularly in schools with large class sizes and limited laboratory resources.

5.0 RECOMMENDATIONS

Based on the findings and conclusions drawn from the reviewed literature, the following recommendations are made to support effective teaching and learning of acid–base titration in Ordinary Level Chemistry.

First, it is recommended that web-based acid–base titration simulation systems be integrated into secondary school Chemistry teaching as a complementary tool to traditional laboratory sessions. Such systems can help overcome challenges related to large class sizes, limited laboratory space, and inadequate equipment by allowing all students to practice experiments individually and repeatedly.

Second, developers of virtual laboratory systems should ensure that simulation content is fully aligned with the Ordinary Level Chemistry syllabus and examination requirements. The simulations should follow standard titration procedures, use familiar laboratory apparatus, and reflect the format and expectations of practical examinations to make them relevant for assessment preparation.

Third, simulation systems should include real-time measurement, calculation support, and immediate feedback mechanisms. Features such as automatic detection of incorrect burette readings, endpoint errors, and calculation mistakes can guide learners, reinforce correct procedures, and improve practical accuracy and confidence.

Fourth, it is recommended that teachers receive basic training on how to effectively integrate virtual laboratories into classroom instruction. Proper guidance from teachers will help students use simulation tools meaningfully, avoid misconceptions, and connect virtual practice with real laboratory experiences.

Fifth, education stakeholders and school administrators should consider adopting lightweight and low-cost web-based simulation platforms that can run on commonly available devices such as computers and smartphones. This will enhance accessibility, especially in resource-limited schools and rural areas.

Finally, future research should focus on evaluating the long-term impact of virtual laboratory simulations on students' practical skills, examination performance, and retention of knowledge. Further studies may also explore the integration of advanced features such as adaptive feedback, guided inquiry, and localized curriculum customization to enhance the effectiveness of virtual chemistry laboratories.

Overall, the implementation of curriculum-aligned, interactive, and accessible acid–base titration simulation systems is strongly recommended as an effective strategy for improving practical Chemistry education at the Ordinary Level.

6.0 ACKNOWLEDGMENT

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