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Beyond the Classroom Walls: Utilizing Remote Virtual Labs to Enhance Learning and Achievement in Science

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Abstract: This research investigates how virtual laboratory simulation platforms can improve learning outcomes and student engagement in experimental science courses. PraxiLabs provides a distinct learning environment by addressing issues with safety, accessibility, and resources that are present in physical labs. Using a combination of approaches, the study looks into how PraxiLabs affects students' comprehension of difficult topics, their ability to develop practical skills, and their satisfaction. According to preliminary results, PraxiLabs promotes an enjoyable educational setting and significantly enhances student outcomes. In addition, the utilization of virtual chemical laboratories is essential for assisting students in developing their skills for chemistry problem-solving. This capacity will be necessary for future experts in the discipline. Assess a real-world lab virtually to render it as authentic as possible, and save money on significantly costly lab supplies, while offering students real-world experience and practice. Giving the students unrestricted access to any STEM virtual lab simulation they desire, whenever and wherever they are, without the inconvenience of needing to visit the lab. Studies highlight how hands-on experiences and active learning are how virtual labs foster students' creativity, critical thinking, and scientific literacy. Students can repeat the same experiment multiple times, see the progress meter record, and receive quick feedback, administrators can manage their educational experience while giving them the freedom they demand. Let more students participate in individualized learning by opening the window of opportunity. Use instructional videos, lab manuals, hint systems, and hazardous ingredient warning labels to encourage students onward.

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Keywords: Virtual Labs, Student Engagement, Learning Outcomes, Accessibility, Mixed Methods.

Introduction

This paper gives deep answers to some research questions in the topic of developing the physical lab course by the utilization of virtual digital labs. The integration of virtual laboratories in education significantly impacts student engagement and understanding of scientific concepts. Research shows that virtual labs can boost critical thinking, scientific literacy, and creativity in students. This, in turn, leads to a deeper understanding of complex scientific concepts. Furthermore, it has been discovered that using virtual chemical laboratories helps chemistry students build critical competences, such as the ability to solve experimental issues successfully and acquire skills necessary for becoming future experts in the subject [1]. Studies have also demonstrated that virtual labs, such as V-Lab, effectively improve students' mastery of core physics concepts, indicating a positive influence on concept acquisition and understanding [2]. In addition, research has shown that incorporating gamification elements like leaderboards into virtual labs enhances student performance, task completion, and self-efficacy. This translates to improved learning outcomes and increased student engagement [3]. The refined Technology Acceptance Model (TAM) further supports the positive impact of virtual laboratories on student performance by integrating usability and learning objectives to optimize the learning process and improve learning outcomes [4].

Science education gets a boost with the integration of virtual laboratories. These digital spaces offer a wealth of benefits for students. Students can do experiments in virtual laboratories in a manner akin to traditional laboratories, which helps them gain a deeper comprehension of theory [5]. They provide science curriculum-aligned interactive simulations to promote student learning and engagement [6]. Virtual labs also support practical experimentation, which is essential for improving learning in science education [7]. Studies also suggest virtual labs can positively impact students' perceptions of the learning experience itself. This aligns with theories like experiential learning and social constructivism, which emphasize the importance of hands-on activities and social interaction in knowledge building [8]. Moreover, the incorporation of virtual laboratories into scientific classrooms can enhance guided inquiry-based pedagogy, science experimentation, and concept creation, offering a dynamic and pertinent learning environment [9].

Students' critical thinking and problem-solving abilities are ultimately strengthened by virtual laboratories, which are essential in bridging the theoretical and practical scientific knowledge gap. Studies reveal that incorporating virtual labs into scientific instruction greatly enhances students' critical thinking skills. [10-12]. Virtual labs transcend the limitations of traditional labs. They allow students to engage in practical activities and gain hands-on experience that might otherwise be impossible. This immersive approach fosters a deeper understanding of scientific concepts and hones students' problem-solving skills. Virtual laboratories provide students with a more thorough learning experience by combining theoretical knowledge with practical application by mimicking real-world experiments and occurrences. Virtual labs push students to become active investigators. They'll be analyzing data, forming hypotheses, and drawing conclusions based on evidence.

Virtual labs ignite a passion for science. Their interactive nature keeps students engaged and fosters a deeper interest in scientific exploration. According to research, including particular laboratory learning objectives in virtual labs improves learning outcomes and student performance. With benefits including modeling chemical processes and facilitating instructional experiments, virtual chemical laboratories are essential for helping students build their experimental problem-solving abilities in chemistry. Additionally, the introduction of animated graphic learning resources in virtual labs increases students' intrinsic motivation, and lab performance is further improved by repeated experimentation and interaction with instructors.

Science education leaps forward with virtual laboratories. Technology unlocks a simulated world of experimentation, making these digital labs essential for students to develop practical skills, especially when traditional labs are limited [13, 14, and 15]. These virtual platforms transform learning from passive observation to active engagement. Students can practice scientific methods, refine critical thinking, and unleash their creativity all within a safe, controlled environment. Through virtual chemical laboratories, students can model chemical reactions, solve experimental difficulties, and carry out research projects that help to enhance their proficiency in chemistry classes. Furthermore, virtual labs help students learn through experimentation, mimic laboratory conditions, and concentrate on behavioral outcomes. These features help students learn scientific concepts more effectively and perform better in actual laboratory settings [14] and [15].

The usage of virtual laboratories offers accessible and affordable alternatives to real lab equipment and facilities in education [16], [17] and [18]. In addition to removing geographical and temporal restrictions, virtual laboratories enable students to participate in practical activities at a distance and drastically reduce the expenses connected with traditional physical labs. Without the need for costly equipment installations and maintenance, these virtual environments provide access to simulations and experiments that replicate real-world settings, enabling repeated practice and learning. The implementation of remote laboratories has been impeded by issues such as high initial costs and technical complexity, although they offer sustainability benefits through worldwide sharing of operations [19]. Virtual labs break down classroom barriers. They empower educators with greater flexibility, allowing them to tailor learning to individual needs. These digital spaces also foster resource sharing, creating a wider learning community where valuable experiences can be accessed by a larger student population. Ultimately, virtual labs ensure equal access to real-world learning opportunities, regardless of location or limitations. This is particularly important in scenarios like the pandemic when distance learning becomes necessary.

Those who use virtual labs as opposed to traditional techniques had significantly higher mean scores on expert thinking exams and decision-making scales. Furthermore, virtual labs fill in the gaps between students' past experiences and knowledge by offering an engaging social learning environment that enhances performance and encourages self-regulated learning [20]. Additionally, it has been discovered that using virtual laboratory media improves students' overall scientific attitude dimensions and boosts their scientific attitudes, which helps them comprehend and internalize scientific topics better.

Virtual laboratory simulations to guarantee safety for students and proficiency

Virtual lab simulations are becoming an essential tool in the fast changing educational landscape, especially in the subject of chemistry, and physics as traditional learning approaches are transformed. These simulations are beneficial because they guarantee student safety, improve learning effectiveness, and give educational institutions affordable alternatives.

Student safety is one of the main priorities in traditional chemistry labs. There are a lot of risks associated with working with fragile glassware, open flames, and dangerous chemicals. By offering a safe, regulated virtual environment where students can conduct experiments without fear of actual harm, virtual lab simulations reduce these risks. A more favorable and laid-back learning environment is produced since students may concentrate only on the learning objectives in this risk-free environment without being sidetracked by possible mishaps.

An enormous library of experiments covering a wide range of subjects is frequently included in virtual labs. This extensive collection guarantees that students are exposed to a wide range of chemistry and physics concepts and acquire a well-rounded practical education. Given the space and budget constraints of many physical labs, the breadth and depth of experiments offered in virtual labs are greater than those in labs.

Virtual labs not only directly assist students and institutions, but they also support environmental sustainability. Conventional laboratories need energy to run, produce chemical waste, and use a lot of resources. Virtual simulations decrease the need for real materials and prevent chemical waste, supporting larger initiatives to encourage ecologically friendly teaching methods.

Chemistry and physics education is undergoing a transformation because to virtual lab simulations, which offer a secure, productive, and efficient learning environment. They give flexible access to a wide selection of experiments, guarantee student safety, improve learning proficiency, and provide affordable solutions. Virtual lab simulations will surely play a significant part in influencing the future of science education, making it more approachable, interesting, and sustainable as educational institutions continue to embrace digital change.

Digital Simulations of Lab Safety

From an early age, students form attitudes toward safety and gain the ability to evaluate risks and dangers. Students arrive in the classroom with a variety of learning experiences. This emphasizes the range of prior knowledge students might possess. A significant number of them lack prior experience in using chemicals or equipment, while some may be adequately equipped to take accountability for risk assessment and safety planning throughout their research. The school science lab gives children the chance to observe, choose suitable practices, and conduct laboratory operations safely, all of which contribute to the development of positive attitudes and habits. The groundwork for learning these abilities is laid by safety and health training. In order for the students to understand that safe procedures are an essential component of science, they should consider the implications and hazards of the experiments they see or do.

The overall goal is to become familiar with all safety guidelines and procedures related to working in a chemical lab, as well as safety signs, material safety data sheets, and how to determine whether a certain powder contains arsenate or not. The goal of the learning objectives is to recognize various safety signals and differentiate between various kinds of signs. Perform an actual experiment while using safety precautions, consider what would be appropriate and inappropriate in a science lab, and review the material safety data sheet. Determine what action to take in the event of a minor mishap.

PraxiLabs is a cutting-edge platform that provides virtual laboratory simulations, allowing students to conduct scientific experiments in a secure, regulated, and interactive setting. It stands apart in the current educational scene. To get the most out of working with PraxiLabs, one must be familiar with its user interfaces and comprehend all of its capabilities. The purpose of this paper is to ensure everyone can get the most out of PraxiLabs safety simulation by offering an instructional guide on how to get started with it.

Using the Platform is how user begin using PraxiLabs. Students must have access to PraxiLabs through their school or through a personal membership in order to use the platform as in Fig. 1.

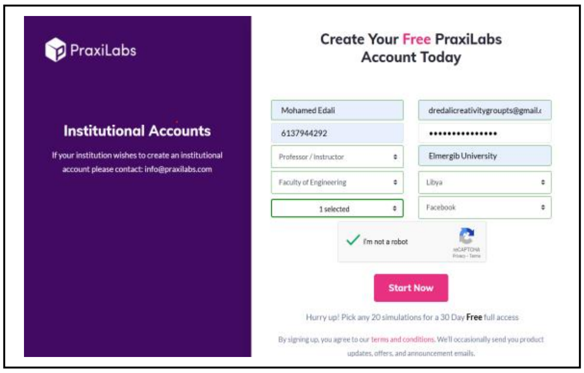

Fig. 1: PraxiLabs log-in credentials

Once access has been granted, proceed to the PraxiLabs website or application and log in using the given credentials. After logging in, the user can navigate the dashboard and see the available experiments and different simulation categories on the main dashboard. It is essential to properly set up the virtual lab setting before beginning any experiment, including the simulation environment. Choosing an experiment from the extensive list of possible simulations is done by selecting the required experiment as shown in Fig. 2 where some chemistry virtual lab experiments are chosen, and in Fig. 3 where some physics virtual lab experiments are chosen as well. There is a summary, goals, and prerequisites for every experiment will follow.

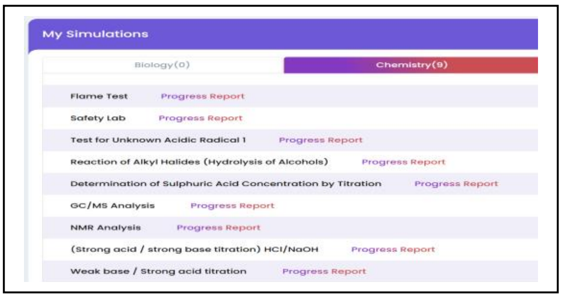

Fig. 2: Chemistry Lab Simulations.

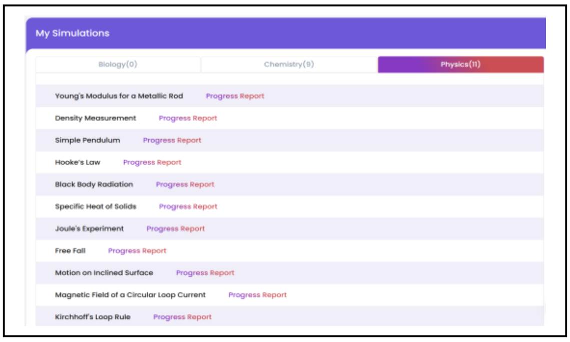

Fig. 3: Physics Lab Simulations.

Practicing Safety Techniques:

PraxiLabs has a high focus on safety, and the platform incorporates safety recommendations and regulations to inform users. Users must carefully read the safety guidelines included in the instructions panel before beginning the experiment. As part of the simulation, virtually outfit a user with goggles and gloves, among other safety gear as shown in Fig. 4. When safety symbols and cautions arise during the simulation, the lab user must pay attention to them. Important information about securely handling materials and procedures is provided by these symbols. Once everything is set up and safety protocols are followed, students can begin the experiment. Detailed instructions are provided, outlining each step precisely. Following them meticulously ensures students conduct the experiment correctly.

Fig. 4: User is guided to wear Safety coat, Googles, gloves

Interacting with the virtual tools and equipment allows one to execute interactive tasks like heating, combining, measuring, and observing reactions. As the platform offers instant feedback during the user experiment, it is crucial to document it. The technology helps the user learn the right process by prompting corrective actions when an error occurs as indicated in Fig. 5. In science, every journey begins with a record. Documenting any observations and findings is the first step on the path to scientific discovery. It is imperative that you document your observations, measurements, and outcomes using the data sheets or virtual notebooks that are provided. One possible way to evaluate the data is by using built-in analysis tools, such as comparison charts, graphing functions, and calculators.

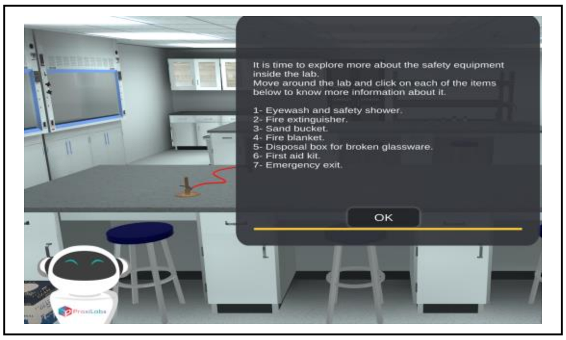

Fig. 5: Guidance throughout all safety equipment inside the virtual lab

After the experiment is finished, giving it some thought and reflection is important. Reexamining the steps by going through them one more to make sure that all instructions were followed accurately as can be shown in Fig. 6. Recognizing any mistakes that were made, by going over the corrective feedback, and figuring out what went wrong. Understanding and comprehension of the experiment can be enhanced by reflecting on it. Any post-experiment queries or points of discussion that the platform provides can be addressed through dialogue of the questions in both english or arabic langauges as indicatied in Fig. 6. If feasible, input from the instructor is essential.

Working on the safety simulation at PraxiLabs is a thorough and rewarding experience that blends academic understanding with real-world application in a secure virtual setting. Through the procedures described in this article, users can run experiments, learn more effectively, and easily use the platform.

Fig. 6: Post-experiment queries, discussions help through dialogue

A video in MP4 that links to a video explaining how to conduct a PraxiLabs Safety Lab's comprehensive training procedure is provided in appendix No. 1 of this paper. PraxiLabs is an essential tool in modern science education since its use ensures safety and promotes a deeper comprehension of scientific concepts and adds clearer insight to the reader through this scientific paper.

PraxiLabs Simulated Chemistry Lab for Educational Advancement

Virtual laboratories have become indispensable resources for improving students' comprehension of scientific ideas in the context of contemporary education. Ninety chemistry simulations are available on PraxiLabs, a cutting-edge virtual laboratory platform. There are fifteen simulations in organic chemistry, fifty-six in inorganic chemistry, and twenty-one in analytical chemistry. This study examines the benefits and useful uses of PraxiLabs in the chemistry curriculum, especially in light of the budgetary challenges that colleges are currently facing. To demonstrate how virtual labs can function as a practical and efficient substitute for conventional laboratory settings, we will also examine in-depth a case study of the Determination of Concentration of Silver Nitrate using Fajan's Method.

The Problem of limited resources and equipment for actual labs' financial limitations may result from the expensive setup and operation costs of a physical chemistry lab, which include large sums of money for chemicals, equipment, and maintenance. Limits to the budget and financial constraints prevent many universities from funding fully functional laboratories, the standard of hands-on learning. Student and staff safety might be seriously jeopardized in underfunded labs when handling hazardous chemicals and complicated equipment.

An overview of chemistry simulations using PraxiLabs fifty-six simulations of experiments in inorganic chemistry. Inorganic chemical synthesis and reactions, qualitative analysis, coordination chemistry, and redox reactions are among the important subjects addressed. Coordination of complex preparation, qualitative examination of anions and cations, and redox titrations are a few examples of investigations. There are fifteen simulations in organic chemistry, with organic synthesis, functional group analysis, reaction processes, and chromatography techniques being the main subjects covered. The twenty-one simulations in analytical chemistry cover several significant topics, including titrations, gravimetric analysis, experimental procedures, and quantitative analysis. These are just a few examples of experiments scientists might perform: analyzing light with a spectrophotometer, precisely measuring sulfate content, and determining the amount of chloride ions using titration.

PraxiLabs Virtual Experiment Case Study to Determine the Concentration of Silver Nitrate

Fajan's method is a titration technique that involves precipitating a halide ion with silver nitrate ($AgNO_3$) to determine its concentration. An adsorption indicator that changes color when it binds to the precipitate is used to identify the endpoint. To conduct this experiment as in Fig. 7, we'll need some key supplies, silver nitrate solution (imagine a liquid with silver and nitrate ions), sodium chloride solution (table salt dissolved in water), a burette (a fancy measuring device), a pipette (a tool for transferring small amounts of liquid), a conical flask (a special container for mixing things), distilled water (pure water for accurate measurements), and an indicator called dichlorofluorescein (a special chemical that helps us see when the experiment is complete). Getting the solutions ready by dissolving a known quantity of sodium chloride in distilled water, one can prepare a standard NaCl solution. Getting the AgNO3 solution ready, the concentration of which needs to be found. Appendix No. 2 of this paper provides a link to an animated video that explains the steps of the PraxiLabs virtual experiment case study to determine the concentration of silver nitrate lab's detailed training procedure.

The burette is first filled and rinsed with the AgNO3 solution to begin the titration procedure. Let's start by measuring out a specific amount of saltwater (sodium chloride solution) using a pipette. Then transfer it to a conical flask. To the NaCl solution, add a few drops of the adsorption indicator. Swirl the flask constantly while adding the $AgNO_3$ solution progressively to titrate. $AgNO_3$ reacts with Cl^- ions when Ag^+ ions are introduced, forming an AgCl precipitate. The solution's color shifts toward the endpoint, signifying the presence of extra Ag2 ions. At the endpoint, note the amount of AgNO3 solution utilized. A handy formula to figure out how much silver nitrate solution it is needed. This formula tells that the number of moles of NaCl (sodium chloride) is equal to the molarity of the NaCl solution multiplied by the volume of that solution which use (in liters). Since silver nitrate and sodium chloride react in a 1:1 ratio, once it its moles of NaCl is known, the same number of moles are needed for silver nitrate. The Molarity of $AgNO_3$ can be computed using the formula

Fig. 7: PraxiLabs virtual experiment case study setting to determine the concentration of silver nitrate

$AgNO_3$ Molarity = Moles of $AgNO_3$ / $AgNO_3$ Volume (L)

Fajan's method is widely recognized for its high accuracy in estimating the concentration of halide ions, that highlights the necessity of experiment accuracy and precision. This method isn't just for the lab, it's a widely used tool across various industries, from environmental research to pharmaceutical development. Scientists use it to analyze the amount of chloride ions in different samples. Teaching the crucial ideas of titration, stoichiometry, and indicator use in analytical chemistry is valuable from an educational standpoint as shown in Fig. 8. A link to a walkthrough video explaining how to carry out the entire PraxiLabs virtual experiment case study Fajan's method titration technique to determine the concentration of silver nitrate is provided in appendix No. 3 of this paper.

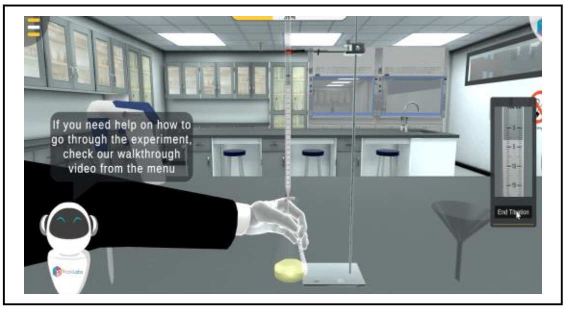

Fig. 8: Titration technique precipitating a halide ion, silver nitrate

Conclusion

A great resource for students and instructors alike, the PraxiLabs virtual chemistry lab offers a variety of experiments that improve learning through hands-on, interactive experiences. PraxiLabs functions as an acceptable alternative for conventional laboratory environments in the face of budgetary and resource limitations, guaranteeing that students have a thorough and hands-on chemistry education. The thorough case study of finding the concentration of silver nitrate using Fajan's method demonstrates how virtual labs may accurately mimic difficult scientific processes, offering students a meaningful educational experience that gets them ready for further scientific endeavors. The practical and educational implications of integrating PraxiLabs within the chemical engineering curriculum are emphasized in this paper. Universities may overcome resource and financial constraints by utilizing virtual labs to give students the practical experience and knowledge they need for both academic and professional success.

خارج جدران الفصول الدراسية: الاستفادة من المختبرات الافتراضية عن بعد لتعزيز التعلم والإنجاز في العلوم

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الملخص:

يهدف هذا البحث إلى دراسة كيفية استخدام منصة محاكاة المختبر الافتراضي معامل براكسي PraxiLab الافتراضية لتحسين نتائج التعلم وزيادة مشاركة الطلاب في مقررات العلوم التجريبية. توفر معامل براكسي بيئة تعليمية مميزة من خلال معالجة مشكلات السلامة وإمكانية الوصول والموارد الموجودة في المختبرات الواقعية. باستخدام مجموعة من الأساليب، تبحث الدراسة في كيفية تأثير معامل براكسي على فهم الطلاب للموضوعات الصعبة، وقدرتهم على تطوير مهارات عملية، وتكسب رضاهم. وبحسب النتائج الأولية، فإن معامل براكسي تعزز بيئة تعليمية افتراضية ممتعة وتحسن نتائج الطلاب بشكل كبير.علاوة على ذلك، يعد استخدام المختبرات الكيميائية الافتراضية أمرا حيويا في مساعدة الطلاب على تحسين مهاراتهم في حل المشكلات في الكيمياء، وهي قدرة ستكون ضرورية للخريجين المستقبليين في هذا المجال. تتيح المحاكاة تقييم مختبر واقعي افتراضيًا لتقديم تجربة أصيلة قدر الإمكان، وتوفير المال على مستلزمات المختبر الباهظة الثمن، مع تزويد الطلاب بتجربة عملية وممارسة في نفس الوقت.توفر المحاكاة للطلاب وصولاً غير محدود إلى أي محاكاة لمختبر افتراضي في مجالات العلوم والتكنولوجيا والهندسة والرياضيات التي يرغبون فيها، وذلك في أي وقت وأي مكان، دون الحاجة إلى زيارة المختبر الفعلي. تسلط الدراسة الضوء على كيفية تعزيز المختبرات الافتراضية لإبداع الطلاب والتفكير النقدي والمعرفة العلمية من خلال التجارب العملية والتعلم النشط. حيث يمكن للطلاب تكرار نفس التجربة عدة مرات، ورؤية سجل مؤشر التقدم، والحصول على ملاحظات سريعة، كما يمكن للمسؤولين إدارة تجربتهم التعليمية مع منحهم الحرية التي يحتاجونها. تتيح المحاكاة المجال لمشاركة المزيد من الطلاب في التعلم الفردي من خلال فتح نافذة للفرص. كما تستخدم مقاطع الفيديو التعليمية وكتب المختبرات وأنظمة التلميحات وعلامات تحذير المكونات الخطرة لتشجيع الطلاب على المضي قدما.

الكلمات المفتاحية:
مختبرات افتراضية، مشاركة الطلاب، نتائج التعلم، إمكانية الوصول، أساليب تعليم مختلطة.

Appendix

1) A link to a video of PraxiLabs Safety Lab's detailed training procedure; (Training_safetyLab_WalkThrough.mp4)

2) A link to an animated video explaining the steps of PraxiLabs virtual experiment case study to determine the concentration of silver nitrate lab's detailed training procedure; (FAJAN Animated Steps AgNO3.mp4)

3) A link to a walkthrough video of PraxiLabs virtual experiment case study to determine the concentration of silver nitrate lab's detailed training procedure; (FAJAN Walkthrough Steps AgNO3.mp4)

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The authors would like to acknowledge the potential of the PraxiLabs virtual laboratory simulation, comprehension, and practical skills development platform in enhancing student engagement and learning outcomes in science education.

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